

HISTORY OF AIR-TO-AIR REFUELLING



Richard M Tanner M.B.E

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Richard M Tanner M.B.E

To the Late Peter MacGregor MBE, BSc (Eng), AFRAeS
A Great Friend and Working Colleague



Aerial refuelling (PUNCH Magazine 1909)

HISTORY OF
AIR-TO-AIR REFUELLING

by
R.M. TANNER MBE



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Table of Contents

Dedication

Title Page

Copyright Page

Foreword

Acknowledgements

Introduction

Chronology

CHAPTER ONE - The Early Years, 1923-49

CHAPTER TWO - The Early Successes, 1949-65

CHAPTER THREE - The Achievements, 1965-93

Technology

CHAPTER FOUR - Boeing B-29 Superfortress

CHAPTER FIVE - Boeing B-29 Superfortress

CHAPTER SIX - Avro Lincoln Mk II

CHAPTER SEVEN - Avro Lincoln Mk II

CHAPTER EIGHT - Boeing B-29 Superfortress:

CHAPTER NINE - Vickers Valiant

CHAPTER TEN - Armstrong Whitworth Argosy

CHAPTER ELEVEN - Mk VII Series I

CHAPTER TWELVE - Mk IX Hose-Drum Unit

CHAPTER THIRTEEN - Mk XI Hose-Drum Unit

CHAPTER FOURTEEN - Mk XIV Hose-Drum Unit

CHAPTER FIFTEEN - Mk XV Hose-Drum Unit

CHAPTER SIXTEEN - Mk XVI Air Refuelling Package

CHAPTER SEVENTEEN - Mk 17

CHAPTER EIGHTEEN - Mk XIX

CHAPTER NINETEEN - Boeing B-29 Superfortress

CHAPTER TWENTY - Boeing B-29 Superfortress

CHAPTER TWENTY-ONE - Republic F-84E
CHAPTER TWENTY-TWO - Mk 20 Under-wing
CHAPTER TWENTY-THREE - Handley Page Victor
CHAPTER TWENTY-FOUR - Vice Versa Air Refuelling
CHAPTER TWENTY-FIVE - Mk 20F Refuelling Pod
CHAPTER TWENTY-SIX - Handley Page Victor
CHAPTER TWENTY-SEVEN - Mk 32 Air Refuelling Pod
CHAPTER TWENTY-EIGHT - Mk 17B Air Refuelling
Package
CHAPTER TWENTY-NINE - English Electric Canberra
B.2 Tanker
CHAPTER THIRTY - Vickers VC10
CHAPTER THIRTY-ONE - Mk 35/2800
CHAPTER THIRTY-TWO - Lockheed C-130
CHAPTER THIRTY-THREE - Lockheed C-130
CHAPTER THIRTY-FOUR - Shin Meiwa US-1
CHAPTER THIRTY-FIVE - Vickers VC10 C
CHAPTER THIRTY-SIX - Lockheed Tristar
CHAPTER THIRTY-SEVEN - Mk XVIIT Hercules
CHAPTER THIRTY-EIGHT - Mk XVIIT
CHAPTER THIRTY-NINE - Boeing 707 Tanker
CHAPTER FORTY - Mk 34 Hose-Drum Unit
CHAPTER FORTY-ONE - Mk 20G Refuelling Pod
CHAPTER FORTY-TWO - Lockheed Tristar

Index

Foreword

Refuelling aircraft in flight is now such a normal part of military flying that it is probably true to say that many of us and probably most of us, at least in the Western World, have witnessed it happening, maybe at an air show where it is always a particular favourite of the crowd.

Because of its normality, few of us if any perhaps, have wondered why, or when, or especially how this procedure can take place safely between two aircraft, of passing thousands of gallons of highly inflammable aviation fuel whilst flying at hundreds of miles and hour and at several thousands of feet above the ground.

The answer to these manifold questions lies here between the covers of this book; the story told by a man who has almost literally, lived and breathed air refuelling for more than fifty years. The author Richard '*Dick*' Tanner has worked on this brainchild of the late Sir Alan Cobham, as Senior and later Principal Design Engineer, from the early precarious days in the late 1940s right up until the latest, highly sophisticated equipment, in use today by the major Airforces throughout the World and must therefore be regarded as perhaps the World Authority in the now preferred so called 'Probe & Drogue' method of achieving this.

A man of immense enthusiasm, Dick Tanner retired in 1988 from Flight Refuelling Ltd. now part of Cobham PLC, the Company responsible for this work and until recently headed up by Sir Michael Cobham, son of the founder, and has spent most of the last fifteen years editing and collating this story from his own personal fund of records and

memories.

From my own days with the Company as a stress engineer in 1956 until my retirement as technical director in 1988 I had the privilege and pleasure of being involved with the author in much of what is related here and I am acutely aware of the great contribution made by him to the important and successful equipment now in use and which has become a very necessary part of all military flying.

The story of the capability to refuel in flight is a very significant and important one in the annals of aviation history and is recorded here in great detail for posterity.

This is a book written for all those who have worked in or on the fringes of the aviation industry as well as in the World's military aviation forces and especially those enthusiasts who seem to populate the world of aeroplanes. It is undoubtedly a definitive work on the subject and a must for the libraries of the Learned Aeronautical Societies of the World.

Frank Behennah FRAeS

Congratulations on a very detailed and interesting history of air refuelling.

Sir Michael Cobham CBE, MA, FRAeS, CBIM

Acknowledgements

The author would like to thank those who have assisted in the compilation of this important aeronautical history.

Initially a very grateful thanks to the late Arnold Croot F.S.I. of 'Abottswood', Christchurch, Dorset who was a great friend over fifty-five years, and who suggested that I wrote this history and greatly helped with the origins of this book.

Michael Vaughn and Keith Ingle of Marshall Aerospace for their enormous help in providing the technical information and photographs of the Tristar Single-point Tanker and C130 Hercules Receiver and Tanker aircraft. Also the information on the Tristar Hose Drum Unit installed in the C130 Hercules aircraft.

S. Lympny Esq of Brize Norton Photographic Services for the excellent photographs of the Vickers V.C. 10 Three-point tanker showing the Mk.17.B. centre line unit and the Mk.32 Wing Refuelling pod. Also to S.A.C. Major of 101 Squadron Royal Air Force Brize Norton of the histories of the Vickers V.C. 10 three-point and the C.MK.1 conversions to two-point together with all of the aircrafts' tail numbers.

George Jenks of the Heritage Centre, B.A.E. Regional Aircraft, Woodford, Cheshire for the technical information on the Victor 1 and 2 Three-point Tanker Aircraft and photographs of the Vulcan Single-point Tanker conversion after the disastrous fire where a lot of information was unfortunately lost. To the late R.A. Funnel of the Royal Air Force Museum, Hendon for providing all the tail numbers of the Victor tanker conversions together with their programme of conversion.

Guy Revell, Assistant Curator, Department of Research and Information Services, Royal Air Force Museum, Hendon for the Tail numbers of the Vickers Valiant Single-point Tanker.

Colin Cruddas late of Flight Refuelling Archives for providing various photographs and the technical write-up of the Avro Lincoln Mk.2. Tanker conversion.

Finally to Frank Behennah Technical Director, Flight Refuelling Ltd (1983-1988) for the Foreword and encouragement he gave to finish writing this history, and for proof reading quite a portion of the later chapters, also to Peter Coles, Editor of Pen and Sword (Aviation) for recommending a change in format which made a better presentation of the history.

R. M. Tanner M.B.E.

Introduction

This book has been written with the intention of recording for posterity the origins of the probe and drogue technique of refuelling in flight, which doubtless had its beginnings in the exhilarating days of 'barnstorming' in the 1920s and '30s, when attempts were made to remain airborne for the longest period of time.

This was probably done more as a stunt than a serious attempt to devise a means of extending the range and increasing the payload of aircraft of the day. But like similar beginnings in other fields of technology, its evolution in this case gave us the now world-famous technique of refuelling in actual flight.

The outstanding pioneer of British aviation, Sir Alan Cobham, after years of gruelling tests and trials, was finally to be the most successful developer of in-flight refuelling. Simultaneously with his success becoming more apparent, conservative authorities began to be impressed by the vital advantages that would obviously result, in particular a system that went into service, not only with our own naval and air forces, but with the rest of the world's forces.

It was at Tarrant Rushton airfield in Dorset that the revolutionary system christened 'Probe and Drogue' was conceived by Flight Refuelling Ltd, the brainchild of the company led by Sir Alan.

I count myself as being very fortunate in becoming a member of the design team during this exciting period, heralding thirty-nine years of service with the company.

Reviewing all this upon my retirement threw into

perspective the lack of, and the need for, a written record of the remarkable enterprise of in-flight refuelling. Having been so involved in it, I trust that I may be forgiven for donning the unaccustomed mantle of a scribe.

R.M.T.
2005

Chronology

CHAPTER ONE

The Early Years, 1923-49

Born 6 May 1894; educated at Wilson's Grammar School; enlisted in Army 1914; transferred to Royal Flying Corps 1917; entered commercial aviation 1919, as a charter pilot; engaged in aerial photography for Aircraft Manufacturing Co. 1920; joined de Havilland Aircraft Co. Ltd 1921; in same year flew round Europe (5,000 miles) and started Spanish airline to Morocco; flew round Europe and North Africa (8,000 miles), and Belgrade-London in one day 1922; flew round Europe, North Africa, Egypt and Palestine (12,000 miles) 1923; won King's Cup Air Race and piloted the late Sir Sefton Brancker to Rangoon and back 1924; flew from London to Cape Town and back, and to Australia and back 1926; started municipal aerodrome campaign 1927; commander pilot of Short Singapore flying-boat on 23,000-mile flight round African continent, and promoted Through African Air Route scheme 1927-8; conducted Air Ministry survey flight down the Nile to Lake Kivu, Belgian Congo, 1931-3; promoted National Aviation Day Ltd, which toured the British Isles, 1934/5; founded Flight Refuelling Ltd, which pioneered refuelling in the air; awarded the Britannia Trophy, 1923, 1925, 1926; RAeC Gold Medal and RIEE Senior Medal 1925 and Gold Medal of Institute of Transport 1926.



Sir Alan Cobham KBE AFC Hon.FRAeS 1894-1973

PUBLICATIONS

Skyways, My Flight to the Cape and Back, Australia and Back, Twenty Thousand Miles in a Flying-Boat

FILMS

With Cobham to the Cape, The Flight Commander, With Cobham to Kivu, The King's Cup

Born 22 February 1927 in Hampstead, London, and educated at Malvern College. Following National Service with the Royal Navy, he won an honours degree in History at Trinity College, Cambridge; subsequently called to the Bar in 1952 and practised until 1955; in that year joined Flight Refuelling Ltd as Contracts Manager; appointed Deputy Managing Director in 1961 and succeeded his father, Sir Alan Cobham, as Chairman in 1969; in 1981 was made a Commander of the Order of the British Empire; upon reaching the age of 65 in February 1992, relinquished the

post of Chief Executive of the FR Group.

After serving on the Equipment Group Committee, was appointed President of the Society of British Aerospace Companies in 1976, and served on the Council; chief extramural activities included Life Vice-President of the Air League, member of the Institute of Directors, Fellow of the Royal Aeronautical Society, Companion of the British Institute of Management, President of the Christchurch Branch of the Royal Aeronautical Society, a Governor of Canford School, a Trustee of the Fleet Air Arm Museum at Yeovilton, and a Trustee of Southampton University Development Trust.



Sir Michael Cobham CBE, MA, FRAeS, CBIM

Born 12 May 1926 in Portsmouth, Hampshire, and educated at Portsmouth Grammar School; student quantity surveyor with Dockerill & Croot, Bournemouth, Hampshire, 1941/2; apprentice at Miles Aircraft Ltd, Technical School, Woodley.

Reading, Berkshire, 1942-6; junior draughtsman at Airspeed Ltd 1946/7; enlisted Regular Army (Royal Electrical Engineers) 1947-9; joined Flight Refuelling Ltd at Tarrant Rushton, Dorset, November 1949, as junior draughtsman; thence to Wimborne in 1965; made a Member of the Order of the British Empire in 1984 for services during the Falklands War; retired November 1988 as Project Manager for in-flight-refuelling projects.



The author, working on the Etendard Refuelling Pod proposal in July 1962

Extramural activities include Senior Scoutmaster with 17th Bournemouth Air Scouts; organized transport for Hampshire Senior Scouts to Austria in 1961; Scoutmaster for 1st Wimborne, Dorset, Scout Troop; Director of archaeological excavations, Tarrant Hinton, Dorset, 1969-73; Chairman, Priest House Museum, Wimborne, Dorset, 1969-73; organized Flight Refuelling Flying Club in

association with Christchurch Flying Club.

In-flight refuelling, as outlined in the Preface, first came about from an uncomplicated ambition to remain airborne longer than other aviators, but after the fledgling days enjoyed by the veterans of the 1914-18 war years, now supplemented by a new generation of aviators to the still phenomenal world of flying, a more serious pattern of success began to appear.

The first moves of this pattern took place in the United States of America in April 1923, at Rockwell Field, San Diego, California, using a de Havilland DH.4B aircraft of the United States Army Air Corps, which was flown by Lieutenants L.H. Smith and J.P. Richter.

The method used was similar to that of the barnstormers, where one of the aircraft was a 'tanker', and the other a 'receiver'. The tanker dangled a 50 ft length of refuelling hose terminating in a 'trigger nozzle', which was grasped by the observer of the receiver, then inserted into the open filler neck of the receiver's fuel tank, and controlled by the observer, fuel being transferred by gravity. By this means a record of 37 hours 15 minutes was achieved on 27/28 April 1923, an event well publicized across the world.

The publicity given to the American success in aerial refuelling encouraged others on this side of the Atlantic to commence similar experiments. In December 1925, Captain Pierre Weiss and Adj Van Caudenburg of Aviation Militaire made numerous demonstrations of aerial refuelling in France with much success, and they continued these, transferring fuel without incident. In June of the same year the Royal Aircraft Establishment at Farnborough in England was directed to investigate the potential of aerial refuelling for the Royal Air Force; however, trials did not commence until February 1924, when two Bristol Fighter aircraft were modified for the experiment. During these only water was transferred between the two aircraft, but they were

considered to be successful, and no further trials were envisaged. Late in 1927 the First Aeronautical Regiment of Belgium's Aéronautique Militaire decided to attempt to break the existing refuelling record. Using two DH.9 aircraft, Adj Aviator Louis Grooji and Sergeant Adj Groenen took to the air on 2 June and remained airborne for 60 hours 7½ minutes, landing on 4 June having broken the existing record by a good margin. Regardless of these events and achievements no significant progress was made until 1929, when Major Carl Spaatz with a crew of four flew a Fokker trimotor monoplane, aptly named The Question Mark, for 150 hours, being supplied with fuel, oil and food by two Douglas biplanes. This achievement started a competition among commercial aviators to improve on the new record. Needless to say, it was broken on numerous occasions, culminating in a 647½-hour flight by Dale Jackson and Forest O'Brien between 21 July and 17 August in 1930. This record remained until 1934, when Al and Fred Kay achieved 653½ hours in a Wright-Whirlwind-powered Curtiss Robin.

In 1930 Squadron Leader (later to become Air Marshal) R.L.R. Atcherley of the Royal Air Force was in the USA attending the National Air Races and witnessing aerial refuelling being carried out, and he soon realized and appreciated its potential, even though still bizarre, to both military and civil users. Consequently on his return to England he commenced work to evolve a safer and more reliable method. He began by eliminating the role of the observer in the receiver, substituting instead what is now known as the 'Cross-Over Contact' method. This involved the trailing of a horizontal line, terminating in a grapnel, from the tail of the receiver, while the tanker trailed a weighted line. Then the tanker, by flying from side to side above and astern of it, enabled a contact to be made between the two lines. Once this was achieved, the refuelling hose could then be passed from tanker to receiver by hauling in the receiver's line. A draft of this method was submitted to the Air Ministry, but it was not considered at the time to be an

improvement over existing methods. However, in March 1935, Atcherley's technique was tested, using a Westland Wallace and Hawker Hart aircraft, and found to be successful. Accordingly it was incorporated in the design specification of future aircraft. Needless to say, its specification was deleted and no further action was taken.



DH.4Bs flown by Richter and Smith, Rockwell Field, USA, 1923

In 1932, Sir Alan Cobham started to take a serious interest in the subject, as he early realized its potential. Sir Alan was of course no stranger to long-distance flying, having made many notable flights to South Africa and Australia in the 1920s. But flights of this nature required stocks of fuel to be positioned en route, and this needed months of forward planning. By refuelling in the air, long-distance flights could be drastically reduced to days rather than weeks, and by the positioning of tankers in suitably based locations non-stop flights were a firm possibility. One of Sir Alan's concerns had always been the fire risk to an aircraft during the take-off period, when it was heavily laden with fuel. The reliability of aircraft engines was still something to be desired, for should

an accident occur the risk of a disastrous fire was extremely high. He contended that by taking off with a minimum quantity of fuel, and then refuelling when safely airborne, the risk of such an occurrence would be minimized. These two considerations inspired him in 1932 to commence personal experiments, using two de Havilland DH.9 aircraft. He was not alone in this field at the time. The intrepid Hon. Mrs Victor Bruce had already entered the refuelling scene, having purchased a Bristol Fighter (G-ABXA) and equipped it as a tanker to announce that she was going to make an attempt on the world's endurance record. Using a Saro Windhover (G-ABJP) as the receiver, she took off and refuelled from the tanker, but the flight terminated after 54 hours 13 minutes due to engine lubrication problems.

Sir Alan, however, continued his experiments into 1934, when he embarked on a non-stop flight from England to India, using an improved method for the tanker to make contact with the receiver. Though still having an observer to control the operation, his tanker now lowered a weighted line to the observer while the two aircraft flew in tandem, one above the other. The line was then used by the observer to haul in the refuelling hose, and, as before, fuel would be transferred by gravity. The first weight to be used to try out this technique was a paint tin filled with lead shot attached to the trailing end of the line. This was then caught by the observer with the crook end of a walking stick, and finally he inserted the hose trigger nozzle into the receiver's fuel tank. During the trials the paint tin fouled the receiver's aileron and nearly caused a disastrous accident. Thereafter a frangible rubber water-container was used; which could be caught by hand if need be. If, however, this fouled the aircraft, it would immediately burst and cause no damage. Having sorted out the weighted-line problem to his satisfaction, Sir Alan prepared for his attempt on the flight to India, using the Airspeed Courier (G-ABXN) as the receiver aircraft. He also played an important role in the design of the Courier, and secured the backing of Lord

Wakefield for the venture. He also requested that it have a capacity of 275 gallons of fuel, with special tankage and other features now evolved for refuelling, but it was decided not to compromise the design of the Courier aircraft.

Nevertheless, it was agreed for the first time that the aircraft could be cleared for a take-off weight of 3,700 lb, and for flight this could be increased 5,050 lb. The tankers employed in this great attempt were Vickers Valentias and Victorias of the Royal Air Force, and a Handley Page W10 (which he had bought from Imperial Airways, in whose service it had been named City of Melbourne).

Unfortunately, after the Indian project the W10 suffered a structural failure and crashed near Ashton Clinton.

Eventually, on 22 September 1934 Sir Alan, with Squadron Leader W. Helmore acting as observer, took off from Portsmouth aerodrome carrying 100 gallons of fuel. En route it was refuelled by the Royal Air Force, taking on board a further 80 gallons. On the approach to Malta the Handley Page W10 was waiting to refuel them. Again this was successful and they headed for the next refuelling point.

However, after a short period of further progress, the throttle linkage of the Courier failed through the loss of a cotter pin, causing the flight to be abandoned. Sir Alan had to make an almost powerless wheels-up landing at Hal Far.

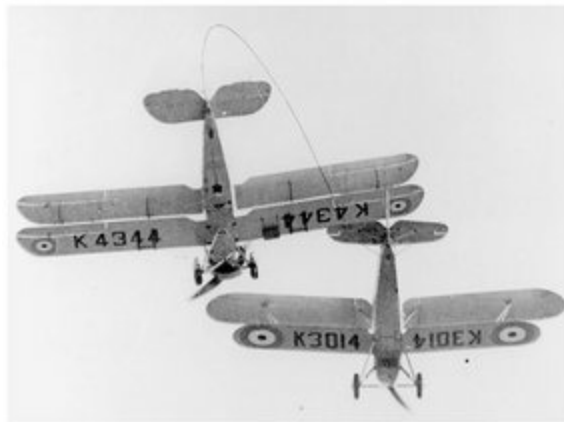


Handley Page W10 refuelling Courier

In 1934 Flight Refuelling Ltd was incorporated as a company for experimental development work on in-flight refuelling. This was sponsored by Imperial Airways and Shell Oil, and continued to be directed by Sir Alan. A number of trials were carried out on behalf of Imperial Airways and the Air Ministry, including various experiments with Vickers B19/17 tankers and Boulton Paul Overstrand aircraft as receivers.



Vickers B/17/19 refuelling Boulton Paul Overstrand



Hawker Hart refuelling Westland Wallace

Also at this time the Hawker Hart was tested as a refuelling tanker and the Westland Wallace as a receiver. But even though these were successful none were ever put to operational use.

Flight Refuelling Ltd eventually moved in 1934 to Ford aerodrome, Sussex, where it took over the work of Squadron Leader Atcherley, who had been continuing his work on the cross-over contact system at the Royal Aircraft Establishment at Farnborough. This proved to be a progressively successful partnership, and the implementation of Sir Alan's and Squadron Leader Atcherley's ideas became known as the 'looped hose' method. In this method the receiver trailed a hauling line terminating in a sinker weight and pawl, while the tanker flew to the side of, and below, the receiver (Fig. 1), the tanker then firing a line with a contactor hook, which, hopefully, crossed over the receiver's hauling line (Fig. 2), and engaged the pawl grapnel (Fig. 3).

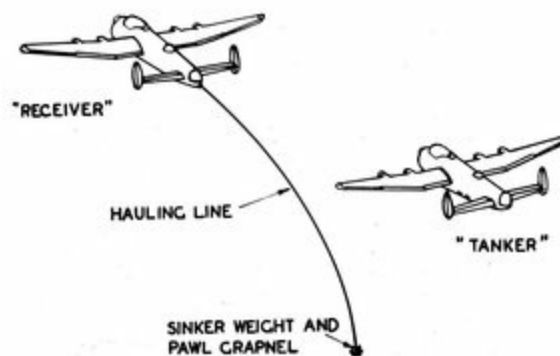


Fig. 1. Receiver Trailing Line

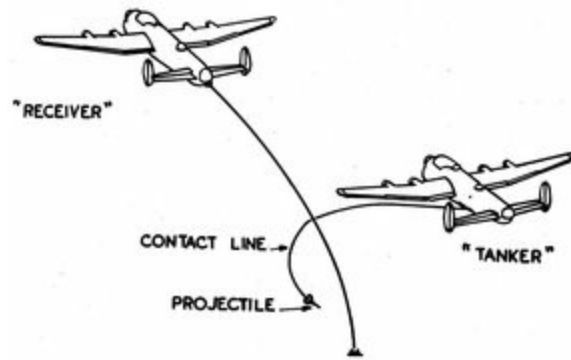


Fig. 2. Tanker firing line

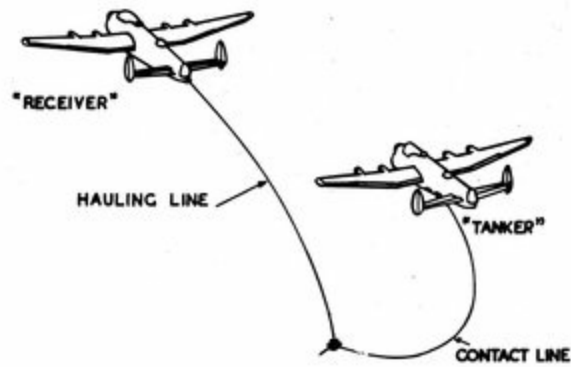
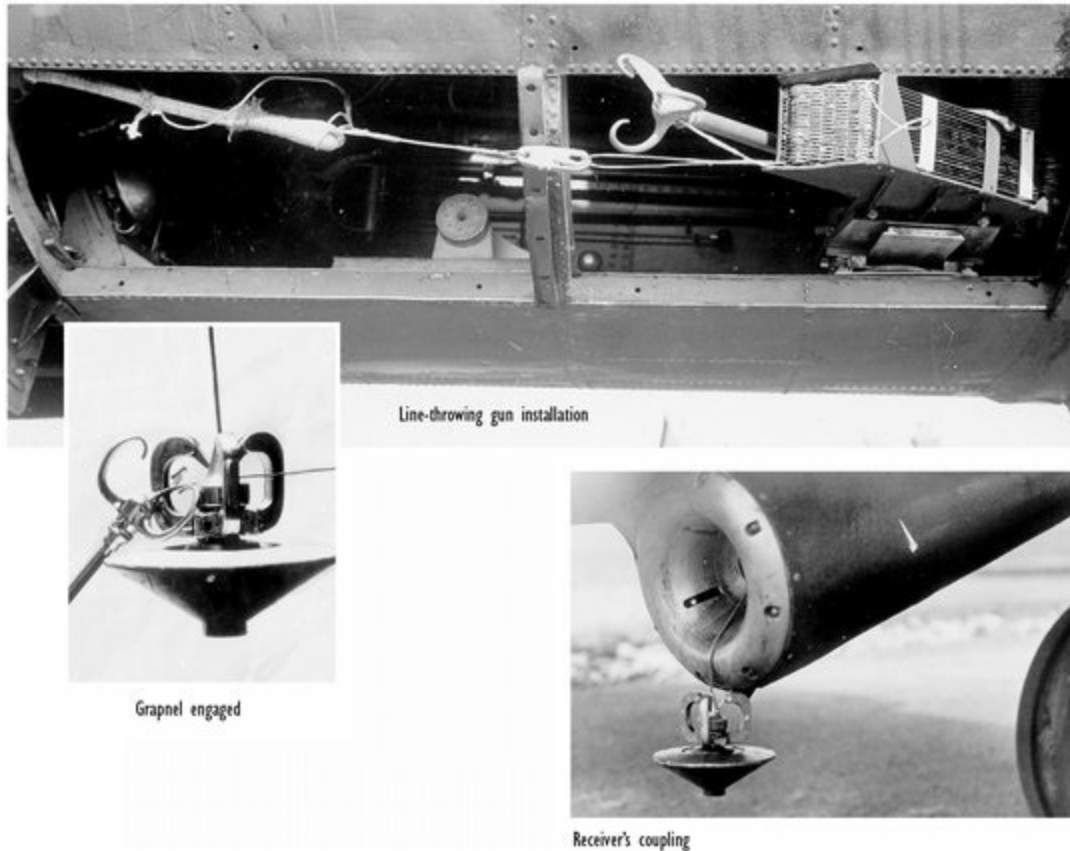


Fig. 3. Contactor hook engaging receiver hauling line



The tanker then hauled in the receiver's hauling line and climbed above the receiver, remaining astern so that when the contactor hook was fully hauled in the hook and the sinker weight were removed from the hauling line and the refuelling hose connected to it, as shown in [Fig. 4](#).

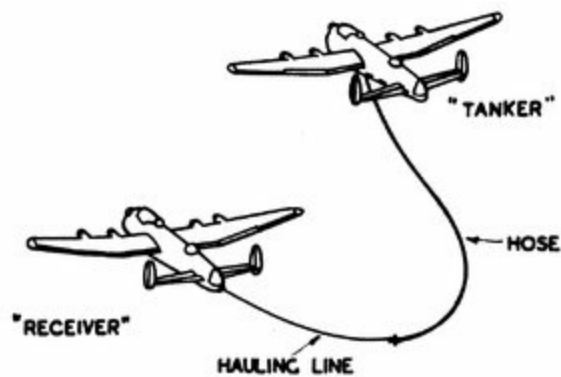


Fig. 4. Receiver hauling in refuelling hose

Once this was accomplished, the receiver hauled in the refuelling hose (Fig. 4) until the nozzle engaged the receiver's coupling (Fig. 5). The tanker and receiver would then fly in formation during the fuel transfer.

On completion the receiver would again trail the released hauling line and refuelling hose. After a certain length had been trailed the tanker would then climb and turn away from the receiver, causing a weak link in the hauling line to break, as shown in Fig 6, achieving both the refuelling and the disconnection. In 1935 Imperial Airways became interested in flight refuelling, and entered into an agreement with the company for further developments of the methods and equipment.

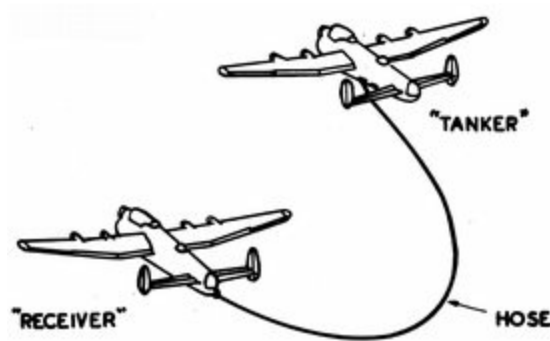


Fig. 5. Refuelling



Refuelling Hose

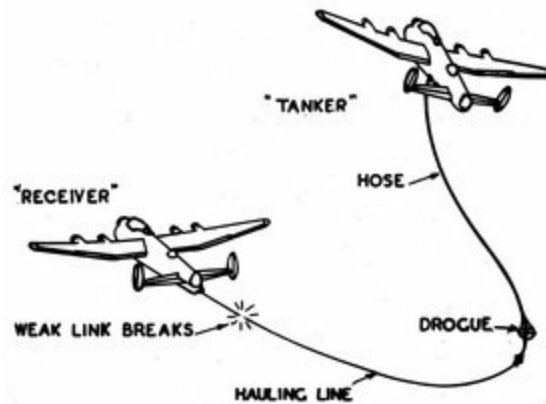


Fig. 6. Breaking contact

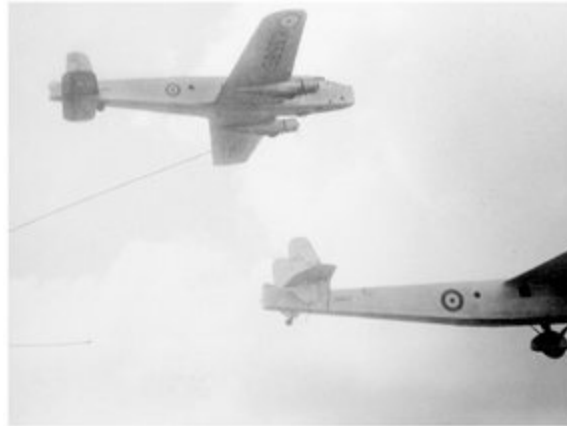
Discussions were held on the possibility of using the system on some of the Empire routes, and also on the projected transatlantic crossings. The Air Ministry also continued to support the development work and provided two Vickers Virginia aircraft for further stages of this work in good faith. During the summer of 1936 the progress made with the two Virginia aircraft was sufficient to accomplish a most convincing demonstration of flight refuelling for the benefit of the directors of Imperial Airways. Development continued with the advent of the Armstrong Whitworth 23 transport aircraft (later to become known as the Whitley bomber) LK3585, together with the Handley Page 51 (prototype Harrow bomber) shown below.

In the summer of 1937 demonstrations were given at the Royal Aircraft Establishment at Farnborough.

The first expression of commercial philosophy behind the whole concept was directed to the transatlantic flying-boat services. A preliminary conference was held at St Johns, Newfoundland, in 1933, at which general proposals for a transatlantic mail service were outlined. This was followed by another in Ottawa, Canada, in November 1935, at which comprehensive agreement on the terms of operation was reached. Representatives of the governments of Great Britain, the Irish Free State, Newfoundland and Canada

agreed to form a joint operating company to come into being in 1936.

Armstrong Whitworth 23 LK3585 and Handley Page 51



Great Britain undertook to build and operate suitable flying-boats and construct the necessary landing facilities in Newfoundland, and Canada's part was to provide the meteorological services in Newfoundland and all the necessary facilities and services in Canada.

British aviation interests never took their eyes off the rich American market, which could be tapped only if a reciprocal operating right could be assured to the United State's interests. A compromise agreement was reached whereby Pan American Airways should operate a service for a period of fifteen years; starting in 1936, Imperial Airways being the 'chosen instrument' of Great Britain.

The Under-Secretary for Air, speaking in the British House of Commons in July 1936, stated:

An experimental service will be established as soon as possible, to be followed by a mail and passenger service on a minimum schedule of two flights weekly in each direction. The service will be

operated by Imperial Airways in association with the Canadian and Irish Free State company, participated in by Pan American Airways on a reciprocal basis. The rights guaranteed by several governments for this service will be exclusive in respect of transatlantic air service for a period of fifteen years.

Hopes for an early start on experimental flights across the Atlantic, using flying-boats, were not realized. Pan American Airways with its 'Clipper Ships' had been ready for some time, but it was not until July 1937 that Imperial Airways was ready with two flying-boats, the Caledonia and Cambria. These two boats were of the Short C-Class Empire type, which could only fly a distance of some 760 miles with a full payload. The Atlantic crossing was 3,300 miles. Nevertheless an attempt was made, with the two flying-boats being delivered unfurnished to save weight, and having six extra fuel tanks installed in the wings and hull to enable the required range to be met. The Caledonia (G-ADHM) made her first experimental crossing from Foynes, Ireland, to Botwood, Newfoundland, on 5 July 1937. Before September ended the Caledonia had completed six crossings, and her sister ship Cambria (G-ADUV) four. Though these flights proved that the Atlantic could be crossed non-stop, there was no payload or passenger-carrying capability, and so further research and experiments were necessary. It so happened that this was a period of novel, even exotic, developments in aircraft design and innovation. One such idea was to catapult the aircraft at take-off, another was pick-a-back, whereby a large machine carried a smaller mail machine on its back, to be released when airborne, and inevitably refuelling in the air. Such schemes were put forward for experimental trials. The pick-a-back and refuelling in flight were chosen, and though this book is relating the history and events of refuelling in flight, some

mention of the pick-a-back take-off is worthwhile. The idea was to have a medium-sized mail-carrying aircraft, loaded to a far greater weight than was permissible for take-off, to climb under its own power on the back of a much larger but lightly loaded carrier aircraft, using the combined power of both aircraft for the initial take-off.

A Short C-Class Empire flying-boat was adapted as the carrier and named Maia (G-ADHK). The smaller mail plane designed for the purpose was a high-winged, four-engined floatplane named Mercury (G-ADHJ), but when they were in the pick-a-back configuration they were known as the Mayo-Composite, after its originator Major R.H. Mayo, who at the time was the general manager (technical) of Imperial Airways. The floatplane Mercury was designed to stand on four supports mounted on the upper surface of Maia's central fuselage, two to each float, the location being a ball and cup, with two further ball and cups situated in a structural box beam in Mercury's lower fuselage. Both the upper and lower aircraft of the Composite were initially flown separately for handling and performance characteristics, all of which were proved to be satisfactory. This was followed on 1 January 1938 with the two aircraft in the Composite configuration completing the first waterborne taxiing trial. By February everything in the experimental trials was going well, and on 23 February 1938, at a height of 700 feet (215 metres), the first separation in flight took place and was totally successful. This spectacular event received great publicity and was hailed as a brilliant achievement. However, it was still necessary to prove the Composite capable of crossing the Atlantic non-stop with a reasonable payload. Unfortunately it was found during the trials programme that the engines fitted to Mercury suffered from a high rate of fuel consumption, which was too high to satisfy the range requirements. Later in the trials programme the engines were changed to a more updated and uprated type that provided more power, together with a much improved fuel consumption. Also at this time some

other aircraft modifications were embodied that enabled Mercury to achieve an absolute range of 3,000 nautical miles. This was proved when Mercury was launched from Maia over Foynes, Ireland, on 1 July 1938, carrying 600 lb of mail and landing in Montreal, Canada, having flown 2,900 miles in 20 hours 22 minutes. Mercury went on to prove the success of the Composite concept by later flying 5,998 miles from Dundee, Scotland, to the Orange River in South Africa. Though the experimental trials showed that aircraft in the Composite configuration could achieve non-stop flights across the Atlantic, it was found to be unprofitable due to the time-consuming return flight, which necessitated Mercury returning on her own with no payload, also landing on this side of the Atlantic at Foynes. However, on the completion of this remarkable feat, the experimental programme was ended by the outbreak of the Second World War. Finally, the carrier aircraft Maia was severely damaged by the German bombing raid on Poole Harbour, Dorset, on 11 May 1941, and subsequently sank.

At the same time as the Mayo-Composite concept was being developed, a second experimental programme for the non-stop crossing received official agreement. It was proposed to refuel the Empire flying-boat in flight, and was sponsored by the then director of civil aviation. This provided Sir Alan Cobham with a long-awaited opportunity, and a chance to demonstrate the latest techniques; taking off with the minimum quantity of fuel but with a good payload, thus increasing the aircraft's range without any major modifications, all implying a gain in air travel.



Mayo-Composite (Maia-Mercury)

The projected programme consisted of two phases. The first phase was to prove the safety and reliability of the equipment and the system during initial flight trials, and that the operation could be achieved with the minimum of extra personnel training. Phase Two was the non-stop crossing, using the northern route in a scheduled service from Southampton to New York, via Foynes in Ireland, to Botwood in Newfoundland and Montreal in Canada, with two refuellings on the westbound crossing and one on the eastbound, the latter being assisted by the prevailing westerly winds.

The first phase used the earlier method of contact between the two aircraft, which differed from that previously described as the looped hose system, though the principle of the receiver hauling in the refuelling hose and engaging the coupling was the same. This method was termed the 'wingtip' method, where the receiver trailed a thin steel cable with a 200 lb lead weight attached to its trailing end, which when released from the aircraft hung almost vertically below it. The tanker came in from behind and below the receiver, making the contact on the receiver's trailing cable, as shown in [Fig. 7](#). As soon as the cable touched the wing the tanker moved away from the receiver and commenced to

climb, the cable sliding along the leading edge of the tanker's wing towards its tip, where it was caught by a hook clipped to the tip of the wing and connected to another cable secured to the underside of the tanker's fuselage. When the tanker was correctly positioned outwards and upwards of the receiver, the hook engaged the receiver's cable and was released under the action of the 200 lb lead weight, and the two cables were now connected and released, falling away from the tanker. The procedure adopted by the looped hose method of hauling the cables and attaching the hose to the receiver's cable was then carried out. To achieve the operation successfully the initial flight trials used the existing Armstrong Whitworth 23 (L.3585) tanker aircraft, and the Empire flying-boat Cambria (G-ADUV), the former aircraft having successfully completed trials with the Handley Page 51 (the prototype Handley Page Harrow bomber). During this part of the programme seventeen flights were carried out, which were in extremely bad weather conditions during January 1938, and were totally successful.

As the operation required two refuellings on the westbound crossing it was necessary to provide the refuelling stations and extra tanker aircraft, the two stations being Foynes in Ireland, situated on the river Shannon, and Botwood in Newfoundland. Three further tanker aircraft were required to complete the operation, and the Handley Page Harrow bomber was chosen for the task. In early 1939, Hugh Johnson (later to become the commercial director of Flight Refuelling Ltd) collected the three aircraft from Handley Page Ltd for the conversion into tankers. In March 1939, two aircraft were given the civilian registrations G-AFRG and G-AFRM. The third aircraft, though delayed; was conveniently registered as G-AFRL, and the Armstrong Whitworth 23 (LK 3585) was allocated a civilian registration of G-AFRX. However, the tanker's wing was something that required further development, and it was not really foolproof. During the conversion of the Harrow aircraft,

attempts were made to improve this by the introduction of two horns being located on the nose of one aircraft (Fig. 8).

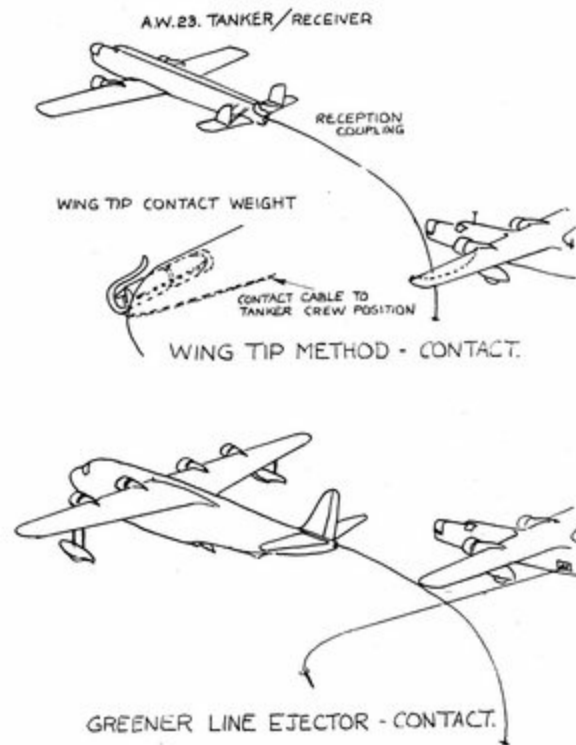


Fig. 7. Wing contact and ejector-gun

This was to enable the pilot to catch the receiver's hauling cable. Nevertheless, despite Hugh Johnson's and Geoffrey Tyson's (later to become chief test pilot of Saunders Roe Ltd) reservations on the new method, trials were carried out, the system being given the title 'The Cobham Trip System'. This method was eventually overtaken when Sir Alan suggested the idea of a line-throwing gun to fire the tanker's contact line across the receiver's hauling line. Hence the revised looped hose system became more foolproof, and virtually guaranteed a safe contact at each attempt. The main development of this revised method was the positioning of the gun within the tanker's fuselage, and this was eventually resolved by positioning the gun 41 degrees forward from the fuselage.

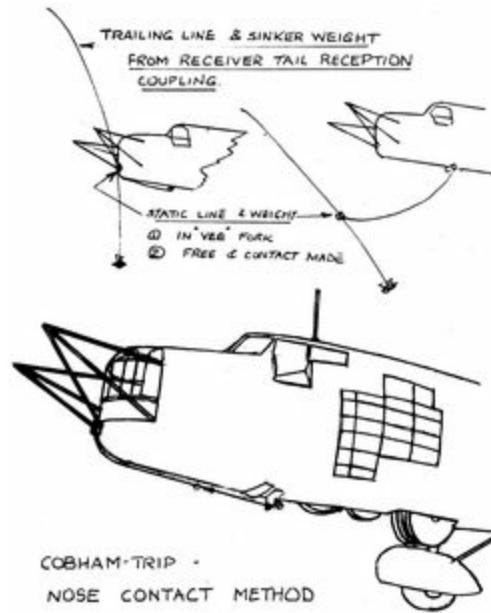


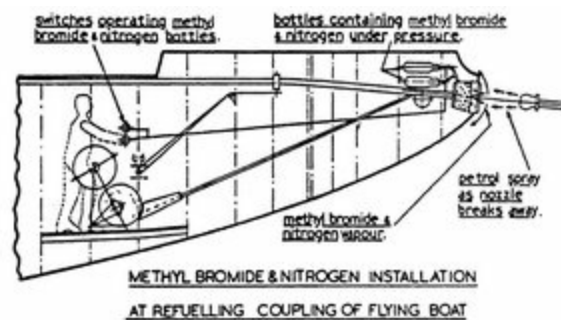
Fig. 8. Horned tanker

The Handley Harrow conversion consisted of three cargo fuel tanks mounted amidships in the fuselage with a capacity of 125 imperial gallons (562.5 litres) of fuel in each tank. These were connected to the aircraft's inboard wing tanks, which could then be fed via a main fuel valve through the rear cargo tank to the hose drum unit. The hose drum unit was located towards the forward end of the fuselage on the aircraft's centre line, and beneath the forward cargo tank; forward of this were the hose guide roller, contact winch (manually operated) and the hauling line reel; above the hose drum unit and forward of the front cargo tank was the hose drum driving winch, which was also manually operated when winding in the refuelling hose on the completion of an operation. All of this is shown in [Fig. 10](#).

The hose-drum winch also controlled the trailing speed of the refuelling hose via a manually operated Girling brake. To the rear of the aircraft was the line-throwing gun, mounted on the port side of the fuselage. To enable the contact line to be attached to the contact winch, the line ran from the winch to the line-throwing gun externally beneath the fuselage, and

was held in position via contact-line catches. When the hose was not in use, though ready for operation, it ran forward from the hose drum onto the hose guide roller, thence externally of the fuselage, the nozzle of which was then secured in a locking vice beneath the hauling-line winch. Besides the capacity of the cargo fuel tanks, which totalled 375 imperial gallons (1,687.5 litres), the aircraft's inboard wing tanks contained another 968 imperial gallons (4,356 litres) of fuel, thus providing a total of 1,343 imperial gallons (6,043.5 litres). Of this total 960 imperial gallons (4,320 litres) were available for transfer to a receiver, and 150 imperial gallons (675 litres) were available from the cargo fuel tanks to supply the aircraft's engines.

Some mention of the Short Empire flying-boat's conversion into a receiver aircraft has to be made, especially as the aircraft was now capable of exceeding the normal all-up weight when refuelled in the air. Incorporated towards the aft end of the fuselage were the manually operated winch that contained the receiver's hauling line, the reception coupling at the stern to accept the refuelling hose, the necessary fuel pipes to feed the transferred fuel to the aircraft's fuel tanks, as shown in [Fig. 9](#), and—one of the most important features—the nitrogen purging system to prevent any fire occurring.



*Fig. 9. Aft end of flying-boat receiver
(showing hauling winch and nitrogen purge system)*

Because the aircraft was now capable of exceeding its normal all-up weight, the first serious considerations were given to the necessity of jettisoning fuel from the receiver, especially in the case of an engine failure, or owing to another emergency when the aircraft had to land on water. Sir Alan and Arthur Gouge of Short Brothers evolved a fuel jettison system, which was eventually installed in the Short S.30 type of flying-boat, Cabot (G-AFCU) and Caribou (G-AFCV), for the second phase of the project. The fuel system of these aircraft comprised nine fuel tanks—three in each wing, two side-by-side in the central wing hull section and one extra overload tank forward of the two hull tanks. When the overload tank was used, fuel was pumped into one of the other tanks. Those that were capable of being refuelled in flight were the starboard inner wing tank (380 imperial gallons, 1,710 litres) and the two hull tanks (280 imperial gallons, 1,260 litres), providing a total of 940 imperial gallons (4,410 litres) of fuel that could be received from a tanker, and this then matched that available from the Harrow tanker. The jettisonable fuel was only permitted to be jettisoned from the two hull tanks and the two inner wing tanks, in all a total of 1,320 imperial gallons (5,940 litres), this being approximately half of the aircraft's total capacity. The jettison system comprised fuel pipes from the inner port wing tank joining pipes from the two hull tanks; these running aft down the hull and discharging through the bottom of the hull, just behind the hull's main step. The starboard inner wing tank was similar but included overflow pipes from the three fuel tanks that were capable of being refuelled in flight. The control of the system was by manually operated fuel valves controlled by the aircraft's engineer, and located above the entrance to the upper deck.

Testing of the system was by the use of petrol in both the inner wing-tanks and paraffin in the hull tanks, during which it was found that there was an ingress of fuel vapour through the aircraft's stern hatches, which necessitated a modification as to the method of sealing these tanks. In addition, so much had been done in the research of fuel systems and their design that the problems of foaming, turbulence and surges had been overcome; this, together with the introduction of shut-off valves, ensured a much smoother system.

The second phase was the Atlantic crossing, in effect to continue the development work begun in the earlier crossings of the Cambria (G-ADUV) and Mercury of the Mayo-Composite concept. Should it be successful it would be the first scheduled service across the Atlantic between England, Canada and the United States. Furthermore it would also open up other air routes throughout the then British Empire, together with a faster service on those already in existence. The scheduled route for this Atlantic development required two air refuellings on the westbound crossing, due to the known headwinds, and only one on the eastbound crossing, due to the now following winds that assisted the aircraft, the tanker having the capability of dispensing 1,000 imperial gallons (4,500 litres) of fuel at each rendezvous. The operational flight plan was from Southampton Water, Hampshire, to Foynes, in Ireland, where the flying-boat would land and take on fuel to the maximum all-up weight allowed, namely 46,000 lb for take-off. Thence it would proceed out into the Atlantic using the northern route, where at an agreed rendezvous it would meet the first tanker out of Rineanna, Ireland, and refuel to a maximum all-up weight of 53,000 lb, an increase of some 7,000 lb above the normal take-off limit. The flying-boat would then continue westbound across the Atlantic, meeting the second tanker out of Gander, Newfoundland, and refuel. On completion of refuelling it would continue to Botwood, Newfoundland, and further fuel would then be loaded for the

journey to Montreal, Canada, where it would again be refuelled for the final leg to New York. The aircraft designated for this development was the Short S.30 Empire flying-boat, an improved design over that of the Short S.23 type, having been strengthened, re-engined with the Perseus engine, which provided more power, and with in-flight-refuelling equipment for the receiver role being incorporated at the design stage. The first aircraft of this type were the Caribou (G-AFCV) and Cabot (G-AFCU). The tankers were the Handley Page 54, the Harrow bomber, of which three were converted, namely G-AFRL, G-AFRH and G-AFRG. Harrow G-AFRL and the Armstrong Whitworth 23 (LK 3585) were to be based at Rineanna, Ireland, for the westbound refuelling, while G-AFRG and G-AFRH were shipped to Newfoundland, Canada, as shown below.



G-AFRG being loaded at Southampton

These two aircraft were based at Gander for the second westbound refuelling, and were under the command of Flight Lieutenant H. Johnson (later to become a wing commander, and eventually commercial director of Flight Refuelling Ltd). The two aircraft were shipped during April 1939, and reached their destination with all of the equipment and crews by the third week of May. In the meantime the flying-boat crews were being trained at Ford, Sussex, with some four hours of flying experience of the

system. The first officer of each aircraft was to be in charge of the refuelling operation, and was to be assisted by the second wireless operator. The captain, or pilot, of the flying-boat required no more than ten minutes of verbal instruction, as he had only to fly a straight and level course during the operation. In actual practice the automatic pilot had charge of the aircraft on more than one occasion during the whole time that fuel was being passed.

During the training programme Sir Alan Cobham flew one of the Handley Page Harrow tankers, as shown below.



Sir Alan Cobham at Harrow controls

On 5 August 1939, the Atlantic service commenced with the Short S.30 Empire flying-boat Caribou (G-AFCV) leaving Southampton on the first westbound flight, receiving its allotted fuel off Ireland from the tanker G-AFRL flown by Geoffrey Tyson. This was followed by Cabot (G-AFCU). A typical refuelling operation is shown in the photograph above-right, during the earlier training, with Cabot being refuelled over Southampton Water in 1939.

In all, sixteen crossings were successfully made, the service providing a once-weekly operation in each direction. On one occasion the air refuelling was not used on account

of the strong westerly wind prevailing at the time, when Captain Kelly Rogers was able to bring Cabot across in ten hours, and on arrival at Foynes still had sufficient fuel to continue to Southampton. The service came to an abrupt end on 1 October 1939, after the return of Cabot owing to the outbreak of the Second World War. The two flying-boats were subsequently pressed into service with the Royal Air Force, and were destroyed in Norway on 1 May 1940. The Armstrong Whitworth 23 (G-AFRX) and Handley Page Harrow (G-AFRL) were both destroyed in June 1940 at Flight Refuelling's home base at Ford, Sussex, during a German air raid. However, the other two Harrow tankers, G-AFRG and G-AFRH, which were based at Gander, Newfoundland, were retained for further work trials, but were abandoned after being used for winter trials and radio calibration work with the Royal Canadian Air Force.



Cabot refuelling from Harrow tanker, 1939

The conclusions drawn from the Atlantic trials were that the system and equipment were safe and reliable for such an operation, and required no major modifications. The average time between making a contact for refuelling took 5 minutes,

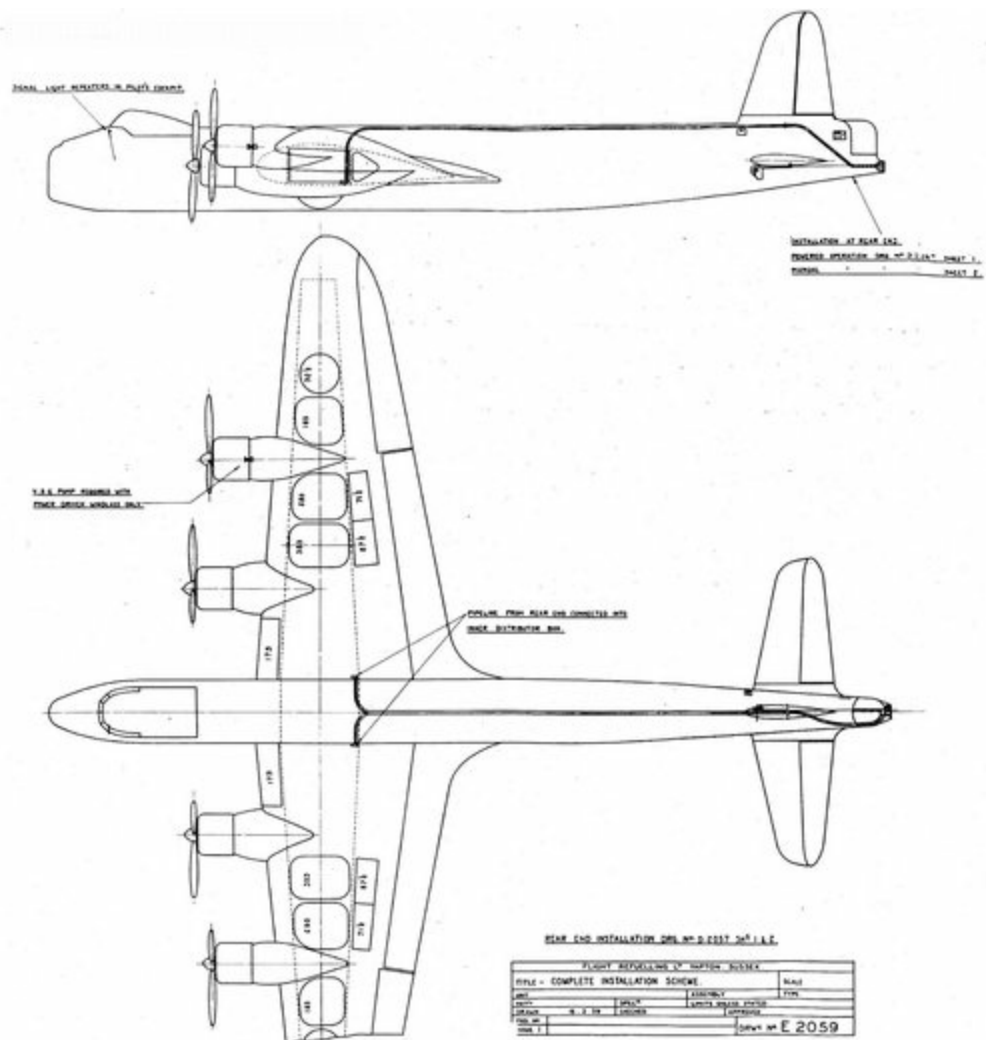
while the time taken to dispense the fuel was in the order of 7 to 8 minutes for 800 imperial gallons (3,600 litres), which was equivalent to 100 imperial gallons (450 litres) per minute flow by gravity. One of the minor modifications recommended was that the hauling equipment be mechanized, which in the long term would save labour, and so hydraulically powered winches and reels were incorporated. The trial not only proved the safety and reliability of the equipment, it also proved that it could be achieved on the North Atlantic route whatever the weather.

While Imperial Airways was looking at the North Atlantic, which would provide a rich market, France and Germany were giving serious attention to the South Atlantic routes. Having established routes from Paris to Dakar in West Africa, and also on the east coast of South America from Natal to Buenos Aires, the French company depended on a ship for the sea crossing between Dakar and Natal for a mail service, which was established as early as 1928. After Air France took over the operation, aircraft were capable of operating a through route.

The German airline Deutsche Luft Hansa similarly used ships to carry the mail between the Canary Islands and Fernando de Noronha from 1930 until 1932, when the first of the seaplane depot ships entered service to provide the necessary refuelling operation for a Dornier Wal flying-boat used for the transatlantic flight. The technique required the flying-boat to land alongside the ship; it was then hoisted on board, serviced and refuelled, and then launched by catapult. The acceleration during the catapult launch was in the order of 4.5 g, and made the technique unsuitable for a passenger service. Nevertheless, the service operated up to the outbreak of the Second World War. The French, however, concluded that a flight refuelled service was required to provide a non-stop service to South America. In cooperation with Flight Refuelling Ltd, they investigated the use of the Latécoère flying-boat as a receiver and the

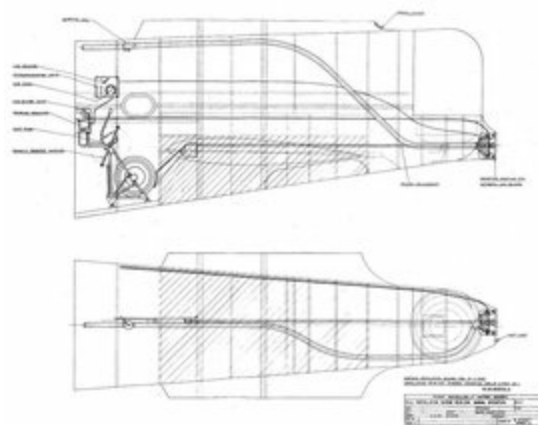
Farman 2234 bomber as a tanker to be employed on the route. However, with the sudden collapse of France in the Second World War, together with the shooting down of an Armstrong Whitworth Ensign airliner, the project naturally collapsed, and the Flight Refuelling representatives, the chief designer, Harry Smith, and the chief engineer, Percy Allison, had to make their way back to England as quickly as possible on one of the few remaining boats to leave Le Havre.

Fig. 11. Short Stirling receiver proposal, 1939



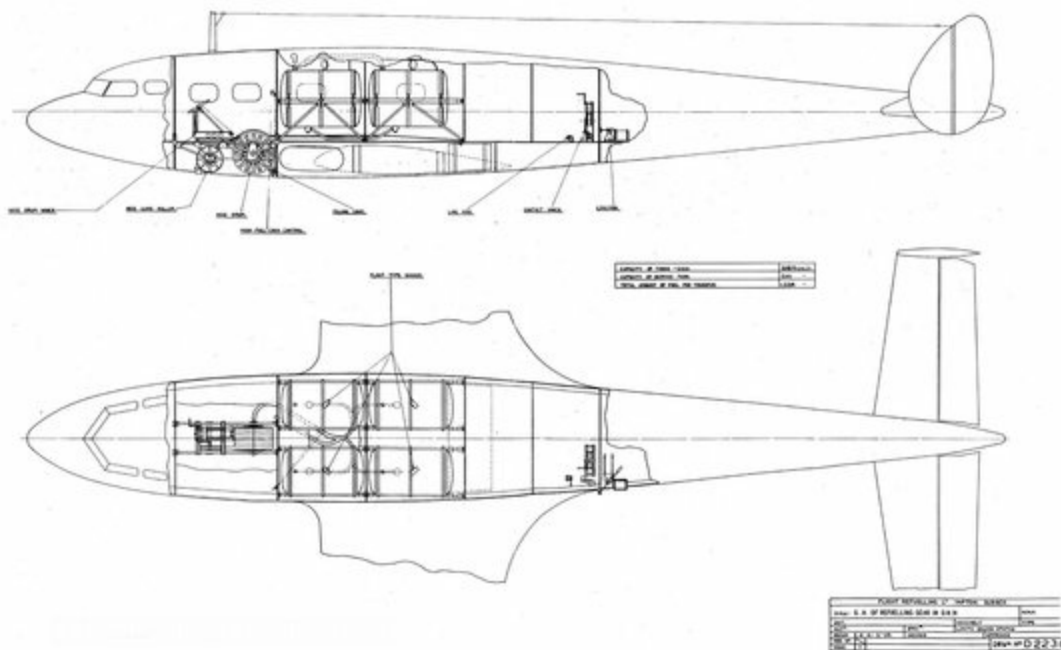
With the Second World War about to commence, the Air Ministry in 1938 requested that studies be made to investigate the technique of refuelling bombers in the air, and to determine what effects, if any, there would be on their performance and load-carrying capabilities. A similar study in April 1939 was made on the Short Stirling into a receiver, as shown in [Figs 11 and 12](#).

The aft end of the Stirling bomber shows that the installation of equipment for receiving fuel was a simple modification, the reception coupling being located beneath the rear gun turret and the fuel line rising to the fuselage roof. The fuel line being connected to the inner collector boxes within the aircraft's fuel system, and the manually operated hauling line winch, is illustrated together with its controls. From the experience gained from the Southampton-New York service later in the year a further option became available—to provide a hydraulically powered hauling line winch, the power being taken from a hydraulic pump mounted on the aircraft's starboard outer engine. Although the study showed that an improvement was achieved in performance, no trials were carried out and the proposal was abandoned.



[Fig. 12](#). Short Stirling receiver aft-end equipment

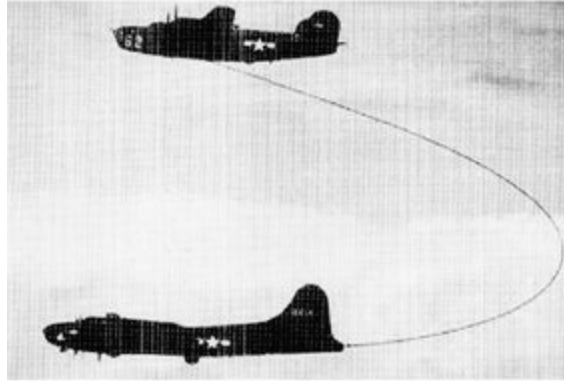
A further study was also made to convert the de Havilland DH.91 Albatross airliner into a tanker, having the capability of dispensing 1,234 imperial gallons (5,553 litres) of fuel. The conversion proposal illustrated the installation of four cargo fuel tanks located amidships of the fuselage, each containing 308 imperial gallons (1,386 litres) of fuel. These were interconnected to feed the hose drum unit mounted forward of the cargo tanks. Forward of the hose drum was the manually operated hose drum winch, and beneath this the hose guide roller. To the rear of the fuselage were the contact reel and line-throwing gun, all of which were mounted on the port side of the fuselage. The total quantity of transferrable fuel was from the cargo tanks—the 1,234 imperial gallons (5,553 litres). The installation proposal for the Albatross is shown in [Fig. 13](#).



[Fig. 13](#). de Havilland DH.91 Albatross tanker, 1939

Various other proposals were put forward until 1940; however, the Air Staff at the time considered them impracticable and lost interest.

Early in 1942, the bombing of the US naval base at Pearl Harbor by the Japanese brought the United States of America into the Second World War. It was not surprising that they soon requested Flight Refuelling Ltd to send technical representatives to Wright Field, Dayton, Ohio, in order to discuss with the Army Air Corps the feasibility of converting the Boeing B-17 Flying Fortress bomber into a receiver, and the Consolidated B-24 Liberator into a tanker, the intention being to make a retaliatory air raid on Tokyo. The discussions came to a satisfactory conclusion, with the Army Air Corps placing an order on Flight Refuelling Ltd for one set of equipment similar to that used in the earlier North Atlantic service of 1939. The reasoning behind this decision was twofold: initially it was for trial purposes, to prove the system was acceptable; and secondly, it was to examine the practicability of carrying out such an operation over such a formidable range. The Pennsylvania Central Airline Company carried out the conversions with the assistance of engineers from Flight Refuelling Ltd, and by April 1943 the flight trials commenced at Elgin Field, Florida. They eventually came to a successful conclusion, the results demonstrating that the Boeing B-17 Flying Fortress bomber's range could be increased to 5,800 miles with a full bomb load. It again illustrated the advantages of refuelling in the air, and was immediately followed by a flight plan being conceived whereby the bombers would fly from the Aleutian Islands, refuel, continue to Tokyo, release their bombs, then overfly to China and land. However, the whole plan was cancelled owing to the length of time it would take, not only to equip and convert the aircraft, but also to train the aircrew. The Consolidated B-24 Liberator refuelling the Boeing B-17 Flying Fortress is shown below



B-24 Liberator refuelling B-17 Flying Fortress

A further factor that also emerged was that the Boeing Aircraft Company was producing the new B-29 Superfortress bomber, which had a greater potential and was about to be introduced into service.

Further plans were being made at the latter end of 1943 for the bombing of Japan by the British from their bases in Burma. There were no Allied bases close enough at this time from which a standard bomber of the day could operate over such a distance, and carry an adequate bomb-load. The Air Ministry came to the conclusion that the only way possible to achieve such an operation was by the means of air refuelling. It was decided in early 1944 that the conversion of the Avro Lancaster bomber into tankers and receivers would be the only practicable way. The conversions were to make use of the looped hose system developed by Sir Alan Cobham through many years of experimentation, not only in the air, but also in various types of aircraft. In January 1944 several schemes for the conversion of the Avro Lancaster bomber into a tanker were put forward, the receiver conversion being similar to that employed in the Short 30 Empire flying-boat of 1939. The first tanker proposal is shown in [Fig. 14](#).

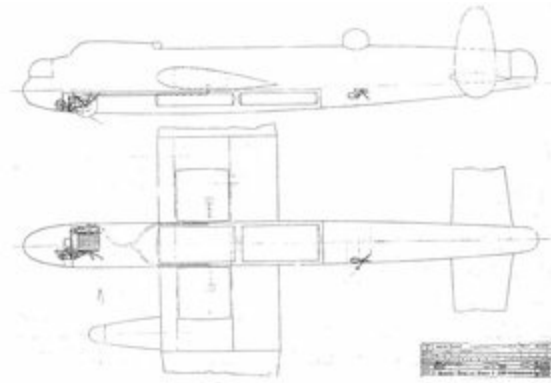


Fig. 14. First Lancaster tanker proposal, 1944

In this proposal the hose-drum unit contact-winch and line vice were to be installed at the forward end of the aircraft's bomb-bay, the fuel being supplied to the hose drum from the No. 1 port and starboard wing tanks, and two additional tanks of 640 imperial gallons (2,880 litres) capacity located at the aft end of the bomb-bay. The line-throwing gun for firing the cross-over contact cable was to be installed aft of the bomb-bay in the rear fuselage, which necessitated the contact cable having to run from the gun along the exterior of the fuselage to the contact winch.

The second tanker proposal, shown in [Fig. 15](#), illustrates that the hose-drum unit and contact winch were in the same position as in the first proposal, but the line-throwing gun was to be mounted from the roof of the bomb-bay at its forward end. This simplified the positioning of the cross-over cable and the connection to the winch, as they were now located adjacent to each other. The fuel system remained identical to that in the first proposal.

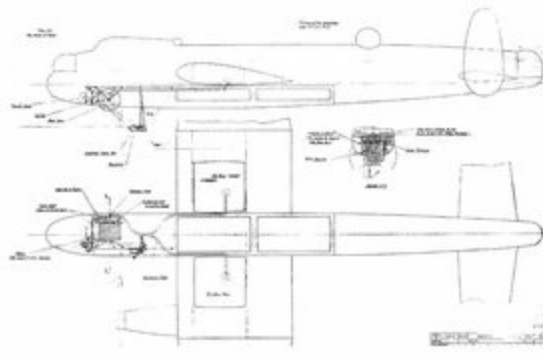


Fig. 15. Second Lancaster tanker proposal, 1944

The third tanker conversion proposal was a totally new concept for the installation of the refuelling equipment, for in all previous aircraft the hose-drum unit and contact winch were installed at the forward end of the aircraft. This concept reversed the earlier principle by putting the hose-drum unit and contact winch towards the rear of the aircraft's fuselage. In this Lancaster conversion proposal the hose-drum unit was to be located at the rear end of the bomb-bay, together with the contact winch positioned adjacent to the operator's compartment. Similarly the line-throwing gun was to be installed on the port side of this compartment. The fuel supply was similar to the previous two proposals, though the two 640 imperial gallon (2,880 litre) tanks were now located at the forward end of the bomb-bay.

It was the third proposal that was accepted for the conversion of Tiger Force aircraft, and initially an order for fifty sets of tanker and receiver equipment was placed. These were for further development of the system and training purposes. It was then intended to convert a total of five hundred tanker and receiver aircraft to mount this long-range operation.

This large force was originally given the codename 'The Long-Range Force', but this was later changed. to 'Tiger Force'. The prototype, the Avro Lancaster tanker (PB.972)

and receiver (ND.648) had both successfully flown by November the same year, which was achieved by the high priority and the enthusiasm of the workforce.

However, once again owing to the progress made in the Pacific theatre of the Second World War by the American armed forces, and the strategic territory that had been recaptured, aircraft could now operate from land bases closer to Japan, and so the whole programme for Tiger Force was cancelled.

It is necessary at this stage to consider the equipment that was to be used in the Tiger Force programme in some detail, for despite the cancellation, the development Lancaster tanker's equipment consisted of two cargo fuel tanks, each having the capacity of 640 imperial gallons (2,880 litres), were installed at the forward end of the bomb-bay, to the rear of which was a hydraulically driven hose drum unit and a hydraulically driven contactor reel for retrieving the tanker's contact line.



Hydraulically driven hose drum unit

The operator's compartment contained all the necessary controls, as shown diagrammatically in [Fig. 16](#), and illustrates the general relationship of the various components that made up the refuelling installation of the

tanker.

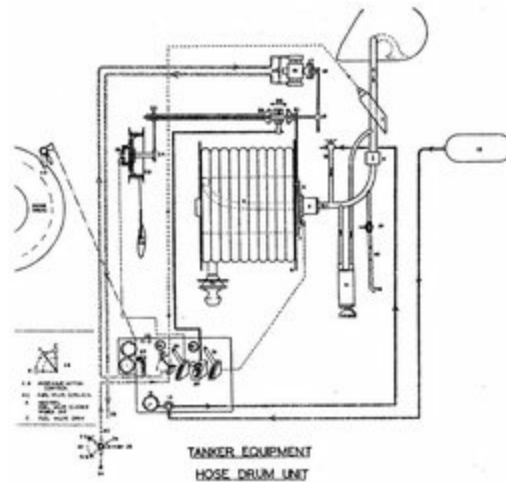


Fig. 16. Diagram of tanker equipment

During the refuelling operation fuel left the cargo tanks by an exit pipe, through a hydraulically controlled shut-off valve, and entered the hub of the hose drum unit on the right-hand side through a rotating seal, and thence into the hose. Between the fuel shut-off valve and the hose drum a siphon pump (Fig. 17) was connected to the fuel system for restarting the fuel flow if the original syphoning process had broken down. Fitted in the bend of the fuel pipe connecting the hose drum was a vent pipe having a sight glass and control valve, which permitted the operator to bleed away any excess fuel pressure remaining in the refuelling hose after it had had to be inhibited with nitrogen gas.

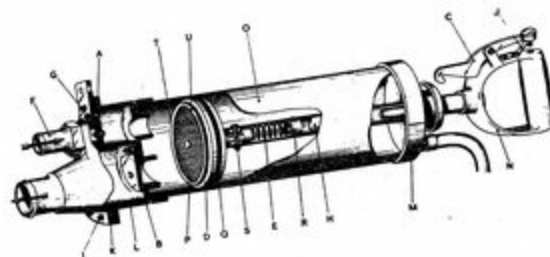


Fig. 17. Siphon pump

A nitrogen purge system was also incorporated to purge the refuelling hose and fuel system of both tanker and receiver prior to and after passing fuel. This system, shown in Fig. 18, together with the fuel piping, consisted of a nitrogen bottle containing gas at 1,800 psi (122 bar), which was connected to a small-bore pipe to a control valve and pressure gauge located on the operator's panel. When the nitrogen valve was selected to 'ON', the nitrogen gas entered the fuel lines after passing through a Palmer reducing valve, reducing the pressure from the 1,800 psi to 8 psi (0.50 bar) above atmospheric pressure. In addition a further pressure-relief valve with an escape to atmosphere was incorporated, which relieved at 10 psi (0.7 bar) for safety purposes.

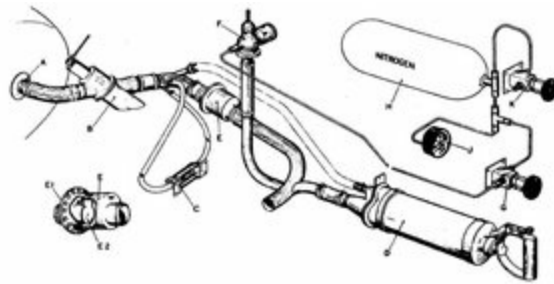


Fig. 18. Nitrogen purge system

The hose drum, as shown in Fig. 19, was mounted in a U-section frame structure, capable of storing 250 feet (76 metres) of 2-inch-bore (5.08 cm) refuelling hose, and was driven by a duplex-wheel-type hydraulic motor powered from the aircraft's hydraulic system, the drum and motor being connected by a chain drive. The main drive shaft of the drum drove both it and the contactor line reel, this being achieved via a simple two-way clutch, which was selected by the operator thus driving either component.

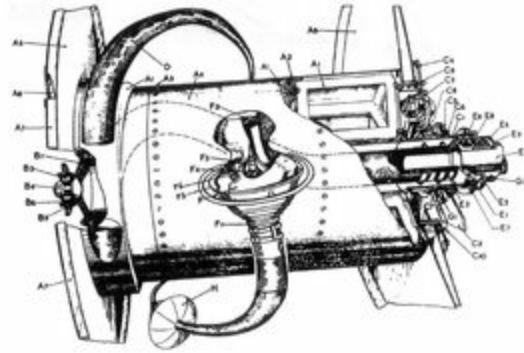


Fig. 19. Hose drum, hose and nozzle

In the hub of the drum, on its right-hand side, a Bendix-type brake was incorporated for controlling the drum's rotational speed. A further pawl stop brake was situated at the periphery of the drum's side flanges, which locked it in position when the hose was fully extended or stowed. Both these brakes were manually operated by the selection of their separate control levers.

The refuelling hose terminated at one end with a ball and coned-shaped nozzle, the ball end of which engaged the receiver's reception coupling. The opposite end was open and attached to the rotating seal in the drum. The construction of the hose consisted of an internal layer of 100-octane petrol-resistant rubber vulcanized to a thicker layer of rubber, both of which, being covered with a helical wire and woven flax cordage, were varnished after weaving. The longitudinal cords providing the major tensile strength, the breaking strain of which was 6,000 lb, while the helical wire prevented crushing when the hose was wound on to the drum; it also acted as a bonding medium to ensure that the electrical potential between the receiver and tanker was balanced.

Attached to the refuelling hose at a point four feet from the nozzle was a drogue, or parasheet, with its shroud lines secured 4 feet further along. The purpose of the drogue was to stabilize the hose when extending or retracting it, thereby

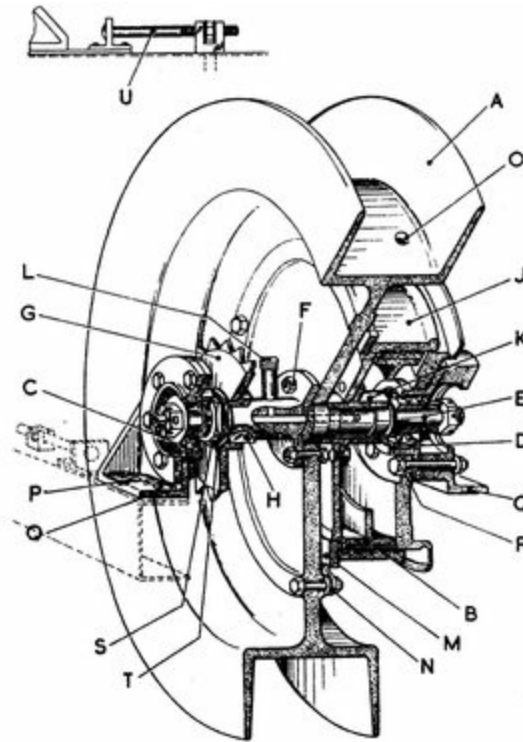
preventing high oscillations being induced. This also removed any possibility of damage being incurred on the underside of the tanker's fuselage during the operation. During the actual refuelling the drogue was automatically collapsed owing to the reversal of the airflow when the nozzle was engaged in the receiver's coupling, as it was now in the forward position.



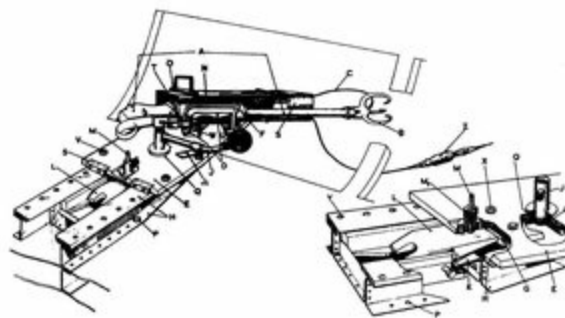
Lancaster tanker, showing drogue

The contact reel ([Fig. 20](#)) wound in the receiver's hauling line once contact had been established with the tanker's line. It was a deep-flanged drum capable of storing 300 feet, or 5 cwt, of unsheathed cable, having a 7-inch Bendix-type brake incorporated in its hub. A further ratchet-type brake was also located adjacent to the Bendix drum brake, which comprised three spring-loaded pawls that engaged a toothed drum. This permitted the contact reel to rotate in the wind direction when hauling in the receiver's hauling line, but prevented the line going into the extended or trailing mode. The drive for the reel was taken from the hydraulic motor used also for the hose drum via the main drive shaft two-way clutch, and was selected by the operator.

[Fig. 20](#). Contact reel



The contactor engaged the receiver's sinker weight located at the trailing ends of the receiver's hauling line, and was simply a steel shaft fitted with a three-pronged head, the prongs being set 120 degrees apart, having an overall diameter of 4 inches. The steel stem was 15 inches in length, while the overall length was 18 inches. This is shown loaded in the line-throwing gun in [Fig. 21](#).



[Fig. 21](#). Line-throwing (contact) gun

The contactor cable container was a rectangular nonferrous receptacle having longitudinal cells built in a honeycomb pattern, each cell 12 inches in length and capable of housing 2 feet of contactor cable. The container was fitted to a metal housing attached to the line-throwing gun prior to the gun being fired for a contact with the receiver's hauling line.

The line-throwing gun that fired the contactor cable was similar to the BSA type used for life saving at sea, and had a Martini action: when fired, the recoil was taken by a heavy spring located in its cylinder. The gun was positioned on the port side of the tanker operator's compartment, which when in the operating position was automatically facing forward at an angle of 41½ degrees.

The operator's control panel, shown in Fig. 22, controlled all of the tanker's equipment with the exception of the line-throwing gun.

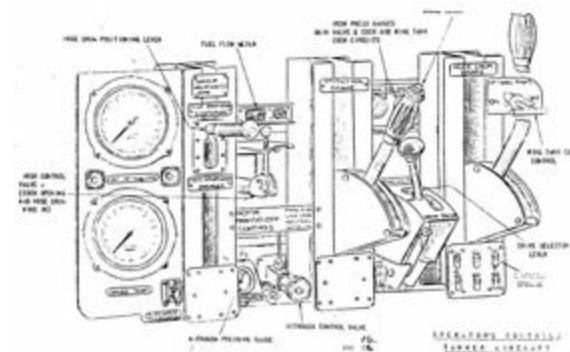


Fig. 22. Tanker operator's control panel

The panel was mounted to the rear of the hose drum unit on its structure, and consisted of the following components:

1. Two capacitor fuel contents gauges, one for the aircraft's inboard wing tanks, the other for the bomb-bay cargo fuel tanks. Two press-button switches beneath these gauges indicated the total quantity in all tanks, or when operated singly indicated the quantity in either the wing

or cargo tanks.

2. Hose drum positioning lever, including a spring-loaded control knob, which protruded horizontally through the panel and when operated engaged the pawl stops at the periphery of the hose drum side flanges, thus locking the drum from any further rotation.
3. Two fuel flow indicators, which when operated in tandem indicated that the fuel was flowing after the main shut-off valve had been opened.
4. Hydraulic power control lever, located beneath the flow indicators and controlling the hydraulic pressure to either the hose-drum motor or the main fuel shut-off valve. The operation of this lever was such that when pulled downwards it provided an increasing power to the hose-drum motor; and when it was released it automatically returned to the 'OFF' position. To select the main fuel shut-off valve a forward gate had to be opened and the lever pushed in a forward direction. It had to be manually returned to the 'OFF' position when such a selection had been made.
5. Nitrogen control and gauge, both of these located at the bottom of the panel beneath the hydraulic power lever. The gauge indicated the nitrogen gas pressure store within the storage bottles, and the manually operated twist valve controlled the flow of gas, when either inhibiting the refuelling hose prior to fuel being passed, or flushing the refuelling hose after an operation.
6. Hydraulic pressure gauges, located above the drive selector lever, indicated the pressure operating the main fuel shut-off valve in either the inboard wing tanks or cargo tank pipe run.
7. Contactor reel brake lever, which actuated the brake shoes fitted in the Bendix brake via a Bowden cable, and had incorporated a hand grip with a thumb-release control when moving the lever to the 'OFF' position.
8. Drive selector lever, linked to the selector dog of the two-way clutch in the main drive shaft for both the hose

drum and contactor reel. In the centre position the dog was in a neutral position, allowing the hose drum to extend the refuelling hose. In the forward position the contactor reel was engaged for hauling in the receiver's hauling line. Similarly, in the rear position the hose drum was engaged for retracting the refuelling hose.

9. Hose-drum brake lever, linked to the Bendix brake in the hub of the drum via a Bowden cable, and actuating the brake shoes, thereby either slowing or stopping the rotation of the drum.
10. Wing tank valve control: if the inboard wing tanks were incorporated in the tanker's refuelling system, adjacent and above the hose-drum brake lever was a wing-tank fuel-valve control, with two positions, 'ON' and 'OFF', either opening or closing the valve.

The tanker fuel system for the purpose of fuel transfer. During this operation the hose drum was connected to the two bomb-bay cargo tanks, each having a capacity of 640 imperial gallons (2,880 litres), and the port and starboard inboard wing tanks 580 imperial gallons in each (2,610 litres). The forward and rear cargo tanks were connected by a large-bore fuel pipe, and the fuel connection to the hose drum was from the rear cargo tank, the fuel transfer being controlled via a fuel shut-off and non-return valve, the latter preventing a reverse flow. Similarly the wing tanks were connected to the main fuel line with a non-return valve and shut-off valve.

The venting system incorporated within the fuel system had a main box vent having a large outlet to atmosphere with a forward-facing air scoop. The scoop provided a pressure of 0.38 psi in the fuel tanks at 160 mph indicated airspeed. This was to provide an additional pressure head in the cargo tanks, as some positions were geometrically below the fuel outlet to the hose drum. Interconnected with the vent box were two main vent pipes, one to the top of the cargo tanks, having four venting points, and the other to the

wing tanks, which each had a single vent point. A further vent point was connected from the vent box to the front and at the top of the forward cargo tank, which provided an automatic pressure balance during ground refuelling and prevented an airlock occurring at the highest level of the tank. From the rear of the vent box another pipe was connected to two vent valves operating in tandem with a short pipe to atmosphere. The purpose of these two valves was twofold. Firstly, when the aircraft was climbing, the pressure rose to $\frac{1}{2}$ psi above the ambient, and the vent valve blew-off to atmosphere, thereby relieving the pressure within the tanks. Secondly, in abnormal steep dives or where the nitrogen gas had been used and the supply exhausted, the ambient pressure being greater than the pressure within the tanks, the vent valve allowed the air to flow into the tanks, raising the pressure inside them and thus creating a balanced system. This latter system was also installed as a safety measure in case the forward-facing scoop had become iced up. The complete fuel and vent system is shown in [Fig. 23](#).

In addition to all the necessary controls and systems, there were a number of accessories that were carried in the tanker:

1. A fire extinguisher was located above the operator's control panel secured by two quick-release clips.
2. A hose wire cutter, having a blade of 12 inches in length and a robust handle.
3. A telescopic crook.
4. A pair of hand wire snips.
5. Spare contactors.
6. A box stowage to hold four contactor line containers.

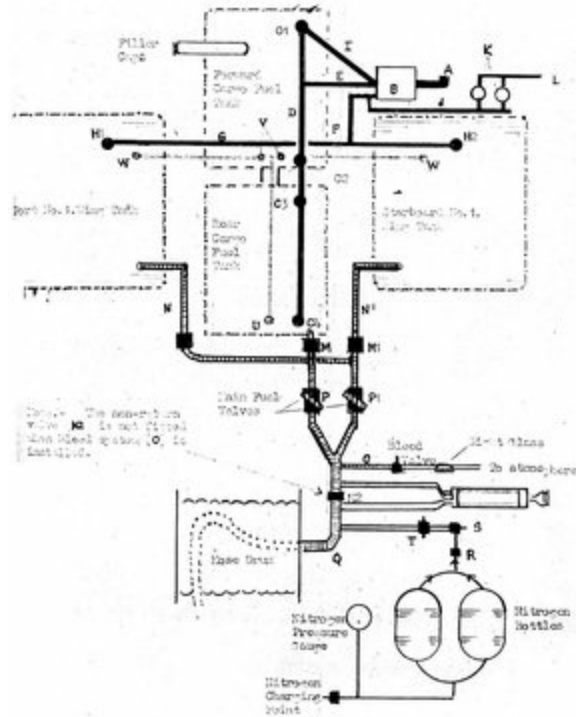


Fig. 23. Lancaster tanker fuel and vent system

These items were carried for emergency use or if any failure of the equipment occurred.

The Lancaster receiver aircraft installation is diagrammatically shown in [Fig 24](#).

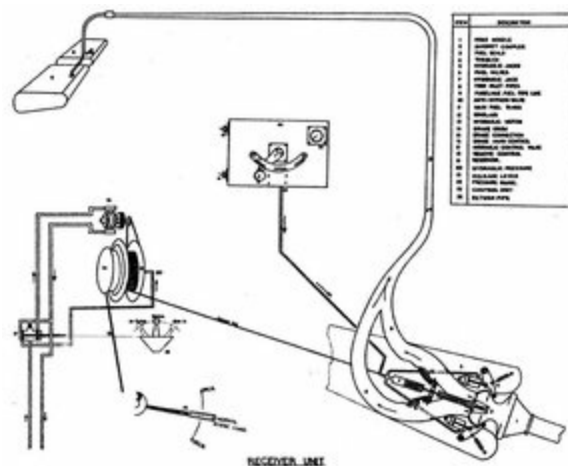


Fig. 24. Diagram of Lancaster receiver equipment

The installation consisted of a bell-mouthed reception coupling which engaged the nozzle of the tanker during an operation, this being located at the aft end and on the lower starboard side of the aircraft's fuselage; a hydraulically driven windlass storing the receiver's hauling line; and the necessary fuel pipelines connecting the reception coupling to the inner port and starboard wing tanks, together with the operator's controls.

The installation, shown in [Fig. 25](#), illustrates the location of the equipment within the aircraft.

The reception coupling, shown in [Fig. 26](#), had a bell-mouthed entry at its rear end to assist the refuelling hose nozzle to enter and engage, the forward end having a bifurcated fuel pipe for connection to the aircraft's fuel system. Externally, between the bell-mouth and bifurcated pipe, were four locking toggles and four single-acting hydraulic rams equally spaced around the coupling's body, which when activated locked the refuelling hose nozzle to the coupling, also causing the nozzle to impinge on seals located within the coupling's mouth. A further hydraulic ram was located at the forward end and external to the coupling's body, and at its centre which was mechanically linked to two flap valves situated in the bifurcated pipe. Mounted externally to the ram were two tension springs also connected to the flap valve linkage, and these held the valves in the closed position when no hydraulic pressure was applied to the ram. Similarly, when hydraulic pressure was applied, the valves were held in the 'OPEN' position. Should there be a hydraulic failure during the refuelling operation the valves were automatically 'CLOSED' via the action of the tension springs, thus providing a fail-safe condition. Through the centre of the coupling's body was a machined orifice to permit the receiver's hauling line to pass through. At the rear end of this was a fuel-resisting seal which mated with a

bayonet coupling attached to the end of the hauling line, so that when the refuelling hose nozzle was engaged a fuel tight joint was achieved. Similarly, a seal located in the bottom of the bell-mouth mated with the ball-shaped portion of the nozzle, so achieving another fuel-tight joint.

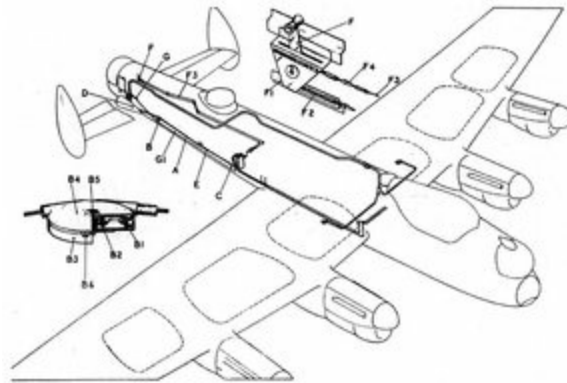


Fig. 25. Location of installation in receiver

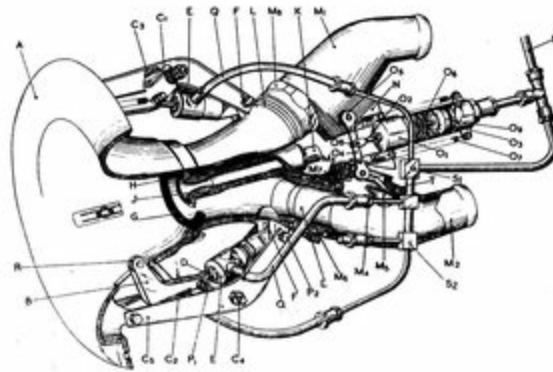


Fig. 26. Reception coupling

The windlass ([Fig. 27](#)) controlled the trailing and winding of the receiver's hauling line, and was capable of storing 500 feet of cable required for the refuelling operation. It comprised a 14 feet diameter x 4½ inches wide light alloy drum located on two journal bearings, and was driven by a hydraulically powered motor and gearbox via a chain drive. The control of the motor was achieved via a hydraulic

control valve having a manual selection lever providing three positions: 'De-Clutch', 'Neutral' and 'Wind'. The drum had secured to it on one side a manually operated 7-inch Bendix brake, and on the opposite side a chain-drive sprocket, and a hydraulically operated piston assembly that was capable of disengaging the clutch located within the drum's hub. The hydraulic power to operate the windlass was taken from the aircraft's hydraulic system through the necessary piping. The clutch within the drum was of the dog type, normally held in the engaged position by a highly loaded compression spring, and provided the driving medium from the hydraulic motor. The selection of the clutch was derived from the hydraulic control valve; when it was selected to the 'Wind' position the clutch was held in engagement by the compression spring, the hydraulic power being supplied to the hydraulic motor, the drum rotating in the wind direction, the speed of this being controlled by the application of the manually operated brake. With the valve selected in the 'Neutral' position no hydraulic power was supplied to either the motor or the clutch, the drum being locked stationary again by the manually operated brake. On selecting 'De-Clutch', the hydraulic control valve supplied power to the de-clutch piston only, thereby disengaging the dog clutch and allowing the drum to freewheel, the speed again being controlled by the application of the brake. This selection permitted the hauling line to be trailed for the contact which was to be made with the tanker aircraft's contact line. On completion of the trailing sequence the drum was held in position by the manually operated brake.

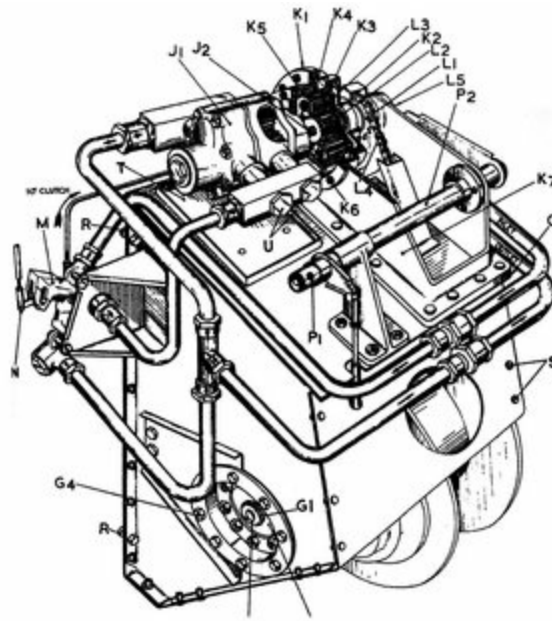


Fig. 27. Receiver windlass

The bayonet coupler and hauling cable are shown in [Fig 28](#). The complete set of hauling cables wound on the windlass drum comprised 150 feet of light static cable with 6 inches of weak link attached to it, these being joined by a further 350 feet of hauling cable terminating with a bayonet-type coupler. The coupler was capable of being connected either to a lead sinker weight for the trailing sequence or the refuelling hose nozzle when the receiver was winding in the hose.

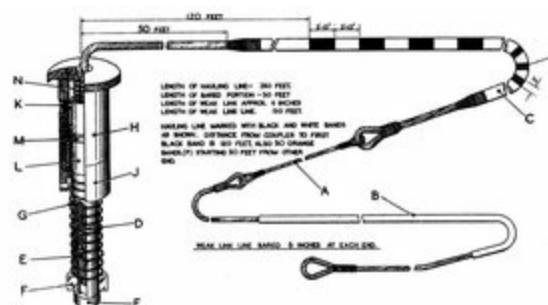


Fig. 28. Bayonet coupler and hauling cable

The static cable was a steel wire rope, 150 feet in length, having a plastic cover with coloured coating, the first 75 feet from the weak link being orange, the remainder black. The breaking strength of the cable was 5 cwt; both ends being finished with a spliced loop, one attached to the windlass, the other to the weak-link cable. The weak-link cable comprised six inches of 3 cwt steel cable looped at each end, one of which connected to the end of the static cable, the other to the hauling cable. The weak link had three specific functions:

1. To prevent undue strain being imposed on the line (in the tanker aircraft), which was secured to the floor of the tanker operator's compartment if the two aircraft should part company when the hauling cable was locked in the vice. The hauling cable would be drawn off the windlass to snap the weak link.
2. To break contact between the two aircraft when the tanker turned to starboard at the conclusion of the refuelling operation. The weak link broke, leaving the hauling cable attached to the nozzle of the refuelling hose. This function applied equally to an emergency breakaway.
3. The electrical bonding between the two aircraft was also broken with the severing of the weak link.

The hauling cable was a steel-wire rope 300 feet in length, having a breaking strain of 15 cwt (1,680 lb). The trailing end had a bayonet coupler swaged to it, the other a spliced loop which joined the cable to the weak link, the spliced loop being flattened to allow it to pass through the machined orifice of the reception coupling. The first 50 feet of the trailing end of the cable were bared for contact purposes, which when made with the tanker's cable balanced the electrical potential between the two aircraft; the remainder being hemp covered and colour marked. Commencing at the looped end, alternate markings were painted in black and orange bands, each 3 inches long, to an extent of 25 feet.

Similarly, commencing at 120 feet from the bayonet coupler (trailing end) were four black and white bands, each 3 feet in length, extending over 25 feet, and commencing and finishing in black.

The purpose of the black and orange bands was to indicate to the receiver operator that when seen by him sufficient cable had been trailed for a contact to be made with the tanker. Likewise the black and white bands indicated to the tanker pilot the best position he should take up to line up his wingtip for making a contact.

The bayonet coupler, illustrated in [Fig 28](#), had the capability of being attached to either the sinker weight used to trail the receiver's hauling cable or the nozzle of the refuelling hose; the latter being achieved after the receiver's hauling cable was locked in the tanker's line vice and was ready to be hauled back to the receiver. The coupler was a tubular spring-loaded device with the hauling cable passing through its centre and terminating in a round-headed swaged nipple. At its lower end two lugs projected which engaged with a bayonet-type slot in both the sinker weight and nozzle, being firmly locked in by the spring action.

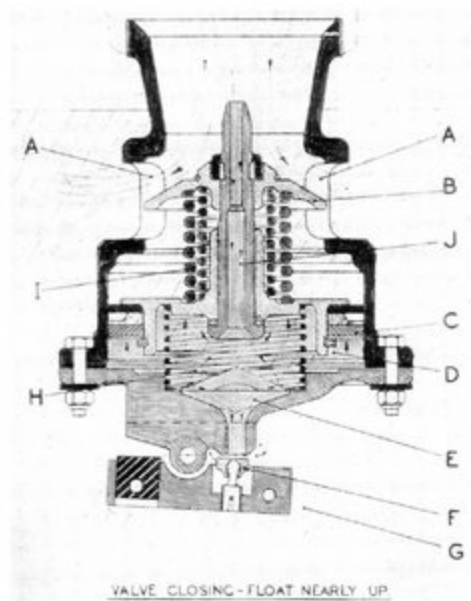


Fig. 29. Fuel tank automatic filling shut-off valve

The sinker weight was a formed shallow-coned weight, having its body cast in lead around a central steel tube which was machined internally to accept the bayonet coupler. It weighed 25 lb, the top being painted white, and it was used for trailing the receiver's hauling cable. It also provided the necessary catenary required for making contact. Attached to the sinker weight was a pawled grapnel, conically shaped, having three vertical pillars, set at 120 degrees apart, each with a spring-loaded pawl attached. The grapnel was split, hinged and locked by means of a hinge bolt and wing nut for easy removal of the skirt that fitted around the body of the bayonet coupler, the head of the coupler fitting into an annular groove. Both sinker weight and grapnel were removed from the receiver's hauling cable once the tanker operator had secured the cable in the line vice.

The fuel system was simply a fuel pipe connected to the bifurcated pipe on the reception coupling, which ran from the aft end of the aircraft's fuselage to the forward end, and was split in two to feed the port and starboard inboard wing tanks via a filling valve. At each inlet to the fuel tanks an automatic filling shut-off valve was incorporated to prevent over-filling and fuel surges occurring. The filling valve illustrated in [Fig. 29](#) was typical of the valves in use at this time, this particular type being a Flight Refuelling Ltd Mk VII, which was servo operated for high-speed refuelling during either a ground or air refuelling operation.

The operation of the valve is worth an explanation because of its simplicity of design. It was fitted within the fuel tank and connected externally to the fuel delivery pipe. As the fuel flow and pressure entered the valve the piston assembly (B and C) moved downwards, the fuel then passing through the ports into the fuel tank. A lightweight spring (H) required a pressure of only 2¼ psi on the domed head (B) to

open the ports. A central aperture (J) allowed fuel to fill the cylinder body (D) while the fuel tank was filling, and also allowed fuel to leak constantly into the tank via a leakage port at (E). As the fuel level in the tank rose, the float that was attached to the valve at (G) shut off the leak at (E), thereby building a pressure on the underside of piston (C). This area being greater than the inlet area, the piston moved upwards, closing off the fuel inlet. Should any high surge develop within the supply pipe due to the closure of the valve, it was automatically damped. The domed head (B) and its shaft had a limited travel inside the centre of the piston, the two portions being kept apart by the powerful spring (I). As surging took place the spring was momentarily depressed, and the domed head opened slightly, so dissipating any 'hammer' effect.

The hydraulic system (Fig 30) was a supply and return system deriving its power from the aircraft's system, and was used to power the windlass, together with the hydraulic rams contained within the reception coupling.

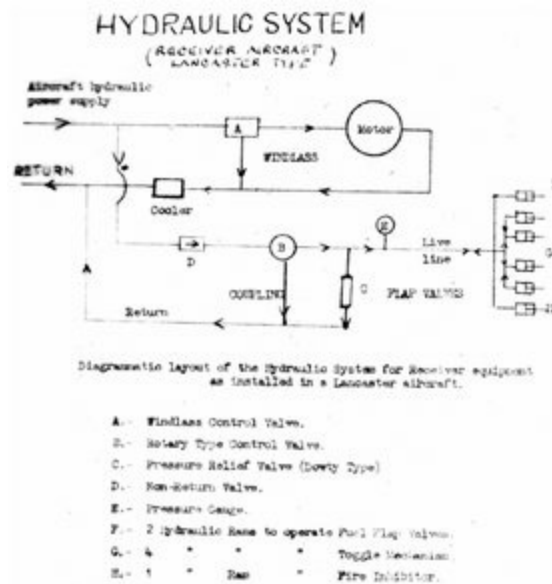


Fig. 30. Receiver hydraulic system

The control of the system was by a two-way manually operated shut-off valve which, when selected, either supplied the aircraft system or diverted it from the engine-driven hydraulic pump to the refuelling equipment. However, when the system was selected to the refuelling equipment, the aircraft was deprived of hydraulic power to its undercarriage and flap systems; this being indicated in the cockpit by the illumination of a red warning light that was only extinguished when the valve had been selected back to the aircraft system, once a refuelling operation had been completed.

The hydraulic power was supplied directly to the windlass motor via a rotary control valve having an internal relief valve. This provided a constant flow of hydraulic oil to the return line of the system, as the pressure to the windlass was greater than that required. The constant relieving by the pressure valve during the refuelling operation gave rise to an increase of temperature within the system, which was overcome by the introduction of a small cooler attached to the outer skin of the aircraft's fuselage.

A further line was teed off the supply line to the rams within the reception coupling via a non-return valve, a manually operated rotary control valve and a pressure gauge, the valve also being connected to the return line. Between the valve and pressure gauge a further relief valve was incorporated across the supply line, set to relieve at 920 psi (62.6 bar). This particular valve provided a safety measure during the refuelling operation, since when the rotary valve was selected to 'Engage' hydraulic pressure was applied to all of the rams in the reception coupling, which moved the four toggles to lock the nozzle of the refuelling hose into the reception coupling, the other opening the flap valves in the bifurcated pipe. When, however, a pull of 1,400 lb was exerted by the hose it caused the pistons within the rams to reverse the direction of the hydraulic pressure sufficient to balance the spring setting within the relieve

valve. Any increase above the 1,400 lb would therefore open the relief valve to the return line, causing an instantaneous drop in pressure; the reception coupling toggles immediately released the nozzle, and the hose pulled away rapidly, drawing with it the receiver's hauling cable, and finally breaking the weak link and contact with the tanker. This method of breaking contact was termed 'Emergency Break', and could be carried out if either aircraft had a problem that required them to separate and curtail the refuelling operation.

THE REFUELLING OPERATION

This was achieved in three stages: firstly the making of a contact between receiver and tanker; secondly the transferring of fuel; and thirdly breaking contact on completion of the fuel transfer.

The initial part of the operation was for the receiver to trail its hauling cable in readiness for the tanker to make the contact with its contact cable. To achieve this the aircraft's hydraulic system was selected to supply the refuelling equipment with the necessary power; the receiver operator selecting the windlass to the 'De-Clutch' position and the brake to 'OFF', thereby allowing the sinker weight at the trailing end of the hauling cable to fall free of the reception coupling, thus pulling the cable off of the windlass; the speed being controlled by the manual application of the brake. When the orange and black markings on the hauling cable were seen by the operator the brake was fully applied, stopping the trailing of any further cable as it had reached the required length for a contact.

Meanwhile the tanker aircraft had taken up a formation position to the starboard side and slightly below and behind the receiver. The tanker operator then selected the aircraft's hydraulic system to the refuelling equipment, and prepared the line-throwing gun for firing. The pilot orientated his aircraft so that the port wing was in line with the black and

white markings on the receiver's hauling cable. Once this was achieved the operator fired the gun, with the gun facing forward at $41\frac{1}{2}$ degrees to port. The contactor attached to the contactor cable took an arc going backwards and crossed the receiver's hauling cable sliding down it, during which time the bared contactor cable contacted the bared end of the hauling cable, thereby balancing the electrical potential between the two aircraft. It continued to slide down until the prongs of the contactor engaged the spring-loaded pawls of the sinker weight's grapnel, making a contact between the two aircraft. The tanker operator selected the hose drum drive motor via the dog-clutch to drive the contact reel, which hauled in the receiver's hauling cable until the sinker weight and contactor arrived opposite the operator's compartment. The contactor reel was then selected to 'Neutral', stopping the hauling process, the sinker weight and contactor being taken on board the tanker and the hauling cable locked into the line vice. The operator disconnected the sinker weight and contactor from the hauling cable by disengaging the bayonet coupler that was then attached to the refuelling hose nozzle. During this sequence the tanker had now climbed above the receiver, remaining on the starboard side and slightly behind. The receiver's hauling cable was released from the line vice, together with the refuelling hose. The hose-drum brake was released and the hose drum was now capable of freewheeling, while the receiver operator selected 'Wind' on the windlass and released its brake, and the hauling cable and refuelling hose were now drawn back to the receiver until the nozzle of the refuelling hose entered the receiver's reception coupling. The receiver operator then selected 'Engage' on the coupling's hydraulic control, which pressurized the coupling's rams, locking the nozzle to it. At the same time flap valves within the coupling were automatically opened, and the windlass set to 'De-Clutch'. The tanker operator applied the brake to the hose drum and engaged the pawl stops to hold the drum in position. Having

achieved the connection between the two aircraft with a fuel line, the system was then purged with nitrogen gas from the tanker's nitrogen system, the gas passing through the refuelling hose into the receiver's fuel system. On completing the purging of the systems, the tanker's fuel valves were opened, allowing fuel to pass from the cargo tanks through the hose drum into the receiver via the refuelling hose. As the tanker was flying higher than the receiver, the fuel flow was by syphon effect and gravity. Should the flow be interrupted for any reason, the syphon pump within the tanker's fuel system was used to restart the flow. Further assistance was also given through the venting system with the ram air applied to the top of the fuel within the cargo tanks from the vent scoop. The average fuel flow rate achieved with the system was better than 100 imperial gallons (450 litres) per minute. On completing the refuelling, the tanker's fuel valves were closed. The inward relief valve in the nitrogen purge system allowed the refuelling hose to drain any residual fuel, followed by purging the system with nitrogen gas. The receiver operator then selected the coupling's hydraulic control to 'Release', thereby depressurizing the coupling's rams and allowing the refuelling hose to be released and the hauling cable to be trailed. When the black marking on the static cable was observed by the receiver operator, sufficient cable had been trailed to effect a disconnection. To achieve this the tanker climbed away from the receiver to starboard, causing the weak link between the static cable to break, thereby severing the link between the two aircraft. The receiver operator wound in the remaining static cable, and likewise the tanker operator wound in the hose by selecting the dog-clutch of the hose drum's drive to 'Wind', also disengaging the drum's pawl stops. On the hose being recovered the brake was again applied and the hose was locked into a securing receptacle, the length of static cable that was attached being also removed. When both operators had completed these tasks the hydraulic systems were selected

to both aircraft's own systems. The receiver, having been refuelled, continued to its final destination, and the tanker returned to its own home base.

The trials for the Tiger Force operation were carried out with the prototype Lancaster tanker PB.972 and receiver ND.648, using the equipment described, and it proved that refuelling could be carried out at an indicated airspeed of 160 mph at any reasonable altitude, over or in cloud and at night, there being no difficulty in illuminating the receiver's hauling cable.

With the end of the Second World War thoughts turned towards civil aviation, raising once again the question of the various ways and means of economically increasing aircraft's payload and range. Parliament at the time was debating the question of the reorganization of air transport in general. Whatever its ultimate form, the long-distance air routes must comprise not only the North Atlantic and European, but also the Empire and South Atlantic routes. Recollection of the North Atlantic Service of 1939 no doubt loomed in the minds of those in the air transport business, recalling the fifteen successful air refuellings of the Short S.30 Empire flying-boats carrying a much greater payload than formerly. The air-refuelling equipment that was produced for the bombing of Japan by the aborted Tiger Force was still available, together with the prototype Lancaster tanker and receiver.

However, in 1942, the Ministry of Aircraft Production, at the request of Lord Beaverbrook (who had become Lord Privy Seal after resigning as Minister for Aircraft Production), called a meeting of all chief designers to discuss the practicability of developing civil transport aircraft of similar range and performance, as a post-war challenge to that already attained by the American manufacturers. The Cabinet had set up an internal inter-departmental committee under the chairmanship of Lord Brabazon of Tara to enquire into types of aircraft needed in the post-war period. The committee reported to the Cabinet

on 9 February 1943 with a recommendation for five types of aircraft, ranging from a London-New York non-stop express airliner to small feeder transports for internal services.

The first of these five projects became known as the 'Brabazon I' for the London-New York route, and was to have priority in design and prototype construction. The Bristol Aeroplane Company was invited to design it, and it eventually became known as the Bristol Type 167 Brabazon I airliner. It was the largest land-based airliner of the period, having a gross all-up weight in the region of 290,000 lb, with eight Bristol Centaurus engines coupled together in pairs, and it was to be capable of carrying 100 passengers. Most post-war airliners had a gross weight of 80,000 lb and 120,000 lb, averaging a third of the Brabazon's weight.

Sir Alan Cobham, however, was convinced that the answer to the problem facing air-transport business, bearing in mind that three American companies were soon to commence their Atlantic service, was to develop aircraft capable of carrying up to 100 passengers and freight, and refuel them in the air. Moreover, the necessary equipment for the conversion of existing aircraft or building new was still available, thus making it feasible to produce either modified or new aircraft at short notice, as well as making them more economical to operate.

Sir Alan invited Mr C.H. Latimer-Needham to join Flight Refuelling Ltd as chief engineer. He was also convinced that by refuelling in flight it would solve the long-distance transport problems of the day. Latimer-Needham took the Brabazon I specification as his basis for an investigation into what size of redesigned aircraft would result if it were to carry a similar passenger load and be flight-refuelled. He considered three types having the accommodation for twenty, fifty and 100 sleeping passengers respectively. The first was based on the Brabazon IIIA specification but later abandoned; the second was designed to incorporate the Brabazon I specification; while the third was intended to be

an airliner suitable for the transport of 100 with sleeping accommodation. All three were initially designed to be capable of flying the London-New York route, with the provision of two refuellings on the non-stop from London and one on the return. The first of his designs was the FR.10 (Fig. 31), capable of carrying twenty sleeping or forty seated passengers, plus a freight load of 4,100 lb; the second was the FR.11 (Fig. 32), which had the capability of carrying either fifty sleeping or 100 seated passengers, plus a freight load of 8,550 lb; and the third was the FR.12 (Fig. 33), with the capability of carrying 100 sleeping or 134 seated passengers, plus a freight load of 14,000 lb. To demonstrate a comparison with the Brabazon I aircraft, the following table illustrates approximately the percentage of fare-paying passengers and freight against each aircraft's overall gross weight, together with its respective size and type of engines.

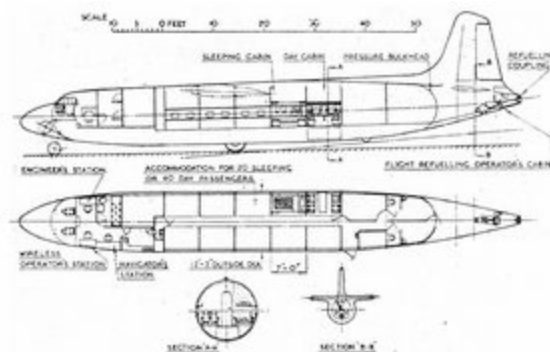


Fig. 31. FR 10 airliner

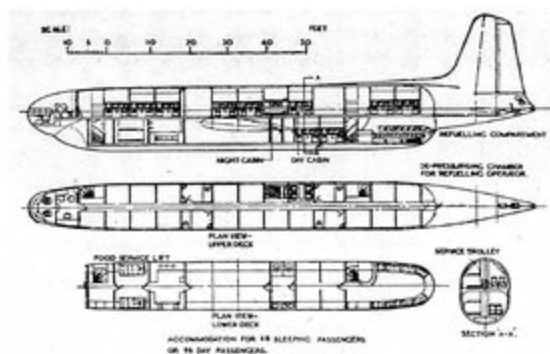


Fig. 32. FR 11 airliner

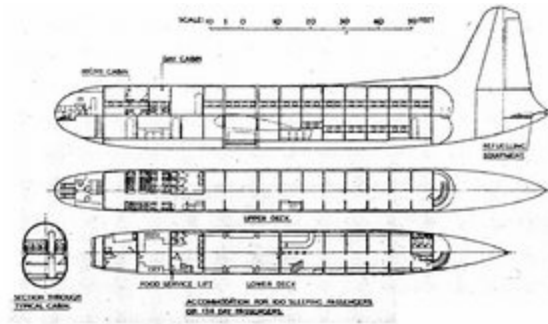


Fig. 33. FR 12 airliner

TYPE No.	Brabazon I	FR.10	FR.11	FR.12
Engines	8 Bristol Centaurus	4 Rolls-Royce Merlin 14.SM	6 Rolls-Royce Merlin 14.SM	6 Bristol Centaurus
Passengers:				
Sleeping	72	20	50	100
Seated	100	40	100	134
Weights Sleeping:				
Gross	275,890 lb	70,000 lb	115,850 lb	185,200 lb
Empty	160,000 lb	44,705 lb	73,650 lb	116,620 lb
Main Dimensions:				
Wing span	230 ft	120 ft	150 ft	195 ft
Fuselage length	177 ft	99 ft	129 ft	146 ft
Range	5,500 miles	2,400 miles	2,400 miles	2,320 miles

The following is an approximate weight analysis indicating the percentage of fare-paying passengers and baggage, plus freight, against the all-up weight of each airliner.

Empty weight	160,000 lb	44,705 lb	73,650 lb	116,620 lb
Fuel, 7 lb/gal	86,000 lb	14,000 lb	19,950 lb	32,200 lb
Oil, 9 lb/gal	3,600 lb	2,000 lb	2,700 lb	2,700 lb
Crew at 175 lb per member	875 lb (5)	1,050 lb (6)	1,225 lb (7)	1,225 lb (7)
Crew baggage	110 lb	120 lb	150 lb	150 lb
Passengers at 175 lb per person	12,600 lb (72)	2,000 lb (20)	8,750 lb (50)	17,500 lb (100)
Passenger baggage, At 100 lb each	7,200 lb	2,000 lb	5,000 lb	10,000 lb
Stewards at 175 lb each	1,225 lb	525 lb	875 lb	875 lb
Mail/Freight	4,000 lb	2,100 lb	3,550 lb	4,200 lb
ALL-UP WEIGHT	275,890 lb	70,000 lb	115,850 lb	185,200 lb
Fare-paying passengers Plus baggage and freight Percentage of all-up weight	8.63%	10.85%	14.93%	17.12%

Even though the figures indicated a more economic operating cost, resulting from the airliners designed by Flight Refuelling Ltd proffering the capability of a higher fare-paying weight percentage, no action was taken by either the Brabazon Committee or the commercial air transport business.

However, the Air Ministry renewed its interest in air refuelling. A panel was formed, its members being representatives of the interested Ministries and airline operators, which finally agreed to a scheduled programme of work for a series of trials to obtain airline operational experience, data on interception techniques, the use of radar equipment, a further development programme dedicated to improvements to the equipment—in short to make possible a first-class, reliable and efficient service. A very comprehensive reporting system was also to be introduced, and independent observers were to be carried during the flight trials. It was agreed that one of the airline operators should be contracted to operate the receiver aircraft.

The object of the trials programme was as far as possible intended to simulate refuelling in the air on a normal airline service route, together with the development of interception

techniques, high-altitude and low-temperature testing; all of which were on a schedule of three refuellings per week over a period of six months. The flight-planning schedule for each operation was predetermined, so that on a given date and time, at a given position, a given quantity of fuel had to be transferred at a given altitude from a tanker to a receiver; each operation to be carried out at a distance of at least 150–200 miles away from the home bases of both the tanker and receiver. One such typical project could be, for example, that on 16 December at 02.00 hours, at a given position off Brest, a tanker should intercept a receiver at the given altitude and transfer 1,000 imperial gallons (4,500 litres) of fuel. Eventually sixty such operations were successfully carried out, thirty of which were night operations. The receiver was operated by British Overseas Airways, with its crews operating the refuelling equipment, the tanker being operated by Flight Refuelling Ltd out of Ford aerodrome in Sussex. The aircraft used were those converted at the latter end of the Second World War for the Tiger Force project.

Serious thoughts now turned to the long-distance, non-stop, passenger-carrying flights, not only the North Atlantic but also the South Atlantic routes. The North Atlantic London–New York was still a problem: no aircraft available at the time had the capability of carrying passengers non-stop on this route. This applied particularly in the winter months, with not only the prevailing westerly winds, but also the low temperatures at this period of the year. A study was therefore made by Flight Refuelling Ltd to prove the economical viability of flight refuelling passenger-carrying aircraft on such routes. The typical aircraft being used at this time on the North Atlantic route were Boeing Stratocruisers, operated by Pan American Airways and British Overseas Airways. During the winter months this type of aircraft could carry a payload of thirty-six passengers from London to New York, with one landing at Gander, Newfoundland; or sixty-three passengers with landings at Shannon, in Ireland, and Gander; the non-stop flight being

impossible with the aircraft's normal fuel capacity. In each case the take-off weight was 135,000 lb; by refuelling in flight at 240 statute miles west of Rinenna, Ireland, and overhead Gander, the payload could be increased to 114 passengers at a take-off weight of 127,150 lb. On the return flight thirty-three passengers could be carried non-stop, for a take-off weight of 135,000 lb, which was only made possible by the prevailing westerly winds (similar to Cabot's crossing in 1939). But with one refuelling overhead Gander, 114 passengers could have been carried, also with a decrease in take-off weight. In addition to the large increase in fare-paying passengers, there were other advantages to be gained. These were that the passenger-carrying aircraft no longer had to land at an intermediate airport and refuel, whereby savings in landing costs were made, wear and tear on the aircraft through having to restart engines, and undercarriage wheel wear were reduced, together with the possible delays through weather and the laborious task of the crew having to fill in the necessary paperwork.

A similar situation applied to the South Atlantic route, London-Bermuda, where again a large reduction in fare-paying passengers arose, especially during the winter months. The costs involved in the refuelling at this time was not excessive: typically, for a non-stop flight from London to New York on a once-daily basis, the cost did not exceed £250 per operation, providing that it took place within 100 miles of the tanker's base. For a further distance of 100 miles an additional £75 would have to be added. Thus, for the London-New York return flight, using Rinenna in Ireland and Gander in Newfoundland as tanker bases, the in-flight refuelling, twice on the outbound flight and one on the return, the total cost would be £750. This sum would easily have been defrayed by the increase in fare-paying passengers, as well as a faster flight, and all in all with an improved profit margin.

Bearing in mind these considerable advantages, early in

1947 a series of trans-ocean non-stop flights using in-flight refuelling between London and Bermuda was conceived. Four specially modified Avro Lancasters were used (G-AHJU and G-AHJV), operated by British South American Airways, and two tankers (G-AHJW and G-AHJT) operated by Flight Refuelling Ltd. These aircraft introduced a secondary radar system that provided an improved interception technique between tanker and receiver, using Rebecca and Eureka equipment. Initially the standard Eureka beacon was employed in the receiver aircraft, which transmitted a signal that was received in the tanker through the Rebecca unit display. However, though satisfactory interceptions were made with this equipment, it became obvious from the considerable variation in maximum ranges that it was not sufficiently stable for long periods of operation. Improved Eurekas were developed by Flight Refuelling Ltd to give a higher output, together with correct maintenance of their preset frequencies. Originally the Rebecca unit was served by one antenna located at the nose of the tanker, and was later modified to a further antenna situated at the tail of the aircraft; switching to enable the use of either was also incorporated. The reason for this modification was that owing to geographical positions of the probable refuelling points, it was apparent that the tanker would have to fly out ahead of the receiver, sometimes for considerable distances and on identical flight paths. A reasonably accurate bearing could only be achieved when the other aircraft was dead ahead or astern. The Rebecca equipment in the tanker received the signal from the Eureka beacon in the receiver, which was displayed at the end of a cathode ray tube.

In the Rebecca display illustrated in (Fig. 34), the centrally shaded column is formed by a green phosphorescent light, the gaps of which provide a calibration in nautical miles. The 'Blip' indicates the position of the receiver aircraft, and the figure indicates that it is 30 miles to starboard of the tanker. By turning the tanker to starboard, thus centralizing the 'Blip', the pilot can fly directly to the receiver and make

contact.

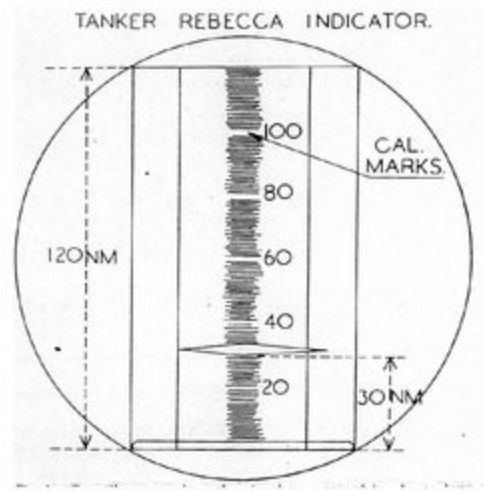
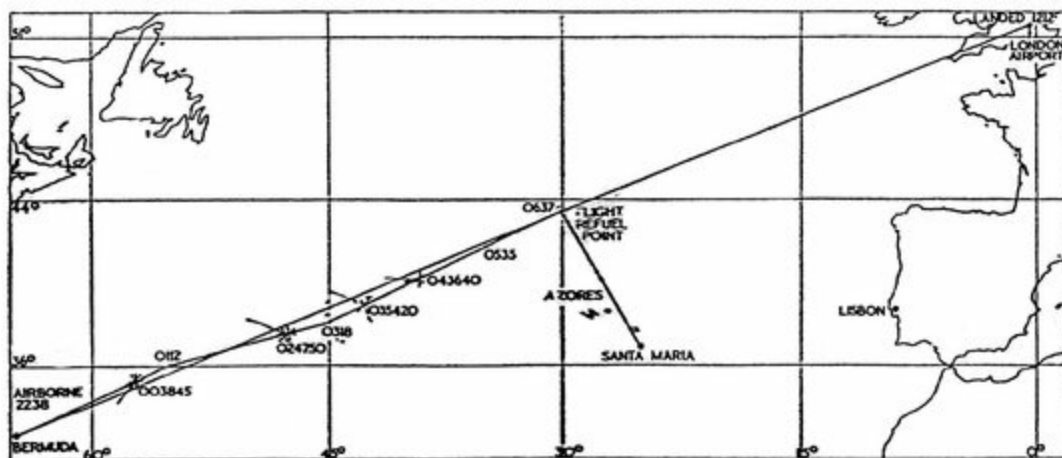


Fig. 34. Rebecca tanker indicator



This reproduction of the chart for the homeward flight, showing the necessary alterations of course, illustrates the need for accurate astro navigation for ensuring a rendezvous in areas not covered by navigational aids.

Fig. 35. Bermuda rhumb-line route

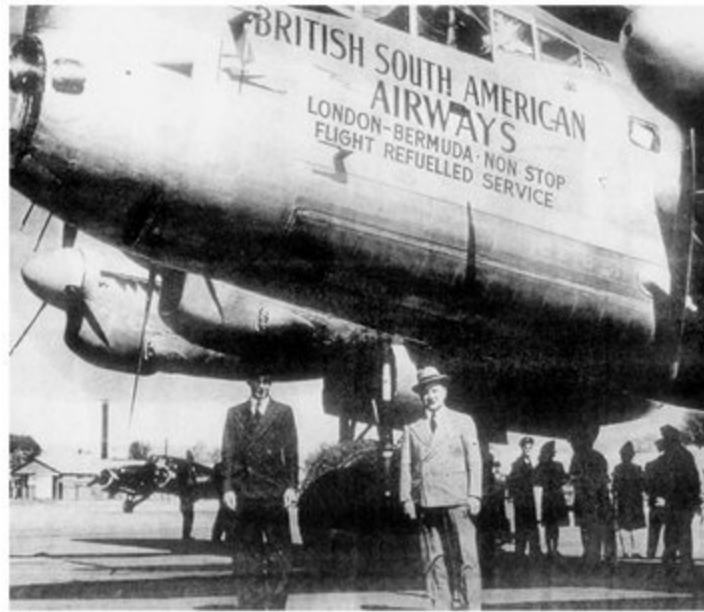
On 28 May 1947, the first non-stop in-flight refuelled flight from London to Bermuda took place. The route was from London Airport to an interception point north of Santa Maria in the Azores, where the receiver was refuelled, thence directly to Kindley Field, Bermuda. Air Vice-Marshal D.

Bennet, who originally flew the Mercury of the Mayo-Composite in 1939, and of Second World War fame for leading bombing raids on the German pocket battleship Tirpitz in Trondheim Fjord, Norway, in 1941, was now the director and general manager of British South American Airways. He took a very great interest in this series of flights, and actually flew with Sir Alan Cobham on the initial flight, and was followed by various crews of that company to prove that no special training was required.

In all, between 28 May and mid-August 1947, twenty-two flights (eleven in each direction) were made, transferring 2,000 imperial gallons (9,000 litres) of fuel on the outbound flight, and half of this amount on the return eastwards; the smaller quantity being due to the favourable westerly winds. Each refuelling took place at an interception point north of Santa Maria, which was varied from flight to flight according to the course the receiver pilot wished to fly. Of the twenty-two operations, twenty-one were successful and one was aborted due to engine problems in the receiver, which had to land in the Azores. Captain R.C. Alabaster, a senior pilot of British South American Airways, made a return flight from Bermuda in 13 hours 34 minutes. On that flight he decided to fly on a direct rhumb-line course ([Fig. 35](#)), making contact with the tanker at a position 450 miles nor-norwest of Santa Maria out in the Atlantic.

This was successfully achieved after having to make a series of course corrections due to a series of weak weather fronts met on the route. His comment on completing the both-directions flight was that he and his crew did not feel as tired as they would have been in the past on shorter flights, which involved an intermediate landing. This was obvious because while in the air they could not be delayed by officials requiring signatures on numerous clearances, flight plans and load sheets. The result of this series of trans-ocean non-stop flights again illustrated the advantages of in-flight refuelling, benefiting with greater reliability of schedules,

since all those tiresome delays such as waiting for the weather to clear at intermediates were borne by the tanker, providing it could take off with sufficient fuel; whereas the long, heavy 'clump' at intermediate airports could delay the normal scheduled passenger-carrying aircraft.



Sir Alan Cobham and D. Bennet, Kindley Field, Bermuda, May 1947

The success of the South Atlantic trans-ocean non-stop flights from London to Bermuda now prompted further trials of this technique to be made across the North Atlantic route, London-Montreal. British Overseas Airways was involved in this final test of the system, proving that non-stop flights could also be achieved on this route. One Consolidated Liberator II (G-AHYD) was modified to a receiver. Flight Refuelling Ltd also purchased four Avro Lancastrian aircraft from Trans-Canada Airlines, converting them to tankers. The route was again similar to that used in the 1939 trials with the Empire flying-boats. Two refuellings were required on the outbound flight and one on the return, tankers being again based at Shannon, Ireland, with the refuelling

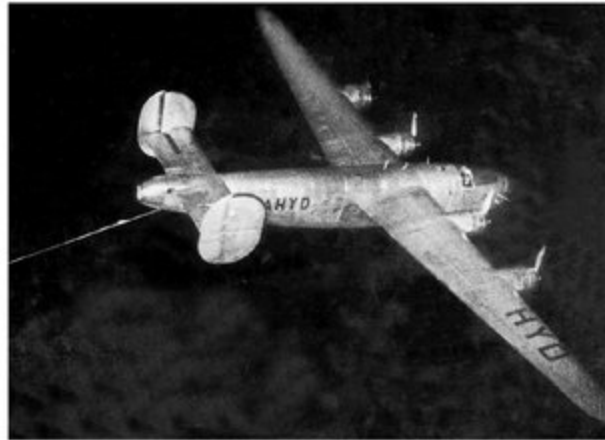
operation being carried out off the west coast, and a second one at Gander, Newfoundland. The trial commenced in February 1948, when the worst period of weather was a known factor. Further, the cloud cover could extend to greater heights than that of the aircraft's maximum ceiling. Despite the weather conditions and strong winds, fifteen return flights (thirty in total) were made from the commencement of the trial into May of the same year, one return interception being carried out 200 miles east of Gander.

In none of these non-stop flights did the aircraft carry fare-paying passengers, though many observers and technicians made the crossing. In spite of these successful trials, the airlines would not commit themselves to the adoption of in-flight refuelling, despite such proofs of economic and technical viability. Various factors reduced the attraction of the technique, such as adverse views of pilots, the concern of passengers during the refuelling operation, and the potential risk. Disappointingly, after these successful series the British authorities showed no further positive interest.

Nevertheless, during the trans-ocean civil non-stop trials; the United States of America began to take a serious interest in air refuelling; the 'looped hose' technique being the only proved system available.

In early 1948, a United States Army Air Force delegation visited Flight Refuelling Ltd to negotiate a contract for the supply of air-refuelling equipment for the Boeing B-29 Superfortress and Boeing B-50A bombers. Initially one B-29 was sent to Flight Refuelling Ltd's new base at Tarrant Rushton, Dorset (to which the company had recently moved), where it was converted to a 'looped hose' tanker. After this the company received an order for sufficient equipment to convert ninety-two KB-29M aircraft to tankers, and seventy-four B-29s and fifty-seven B-50As and B-36s to receivers; the conversions being carried out in the United States. This was designed to give the Americans a substantial increase in the

range of their heavy bombers, notably the capability of carrying nuclear warheads across the world.



Liberator II G-AHYD refuelling at night at 9,000 ft, 1948

The 43rd Air Refuelling Squadron of the United States Air Force demonstrated this capability when it achieved an air-refuelled non-stop round-the-world flight; for which B-50 bombers were specially converted to receivers. Accordingly, the second Lucky Lady set off from Carswell Air Force Base, in Texas on 26 February 1948, returning there on 2 March, having been refuelled over the Azores (3,800 miles), Darharan (5,200 miles), the Philippines (5,300 miles) and Hawaii (5,300 miles). The total flight time was 94 hours 1 minute, the total distance flown being 23,108 miles. Four tankers were based near each refuelling point; two to make the actual contact and transfer of fuel, the other two as reserves in case of any failure.

It is also worth a mention that at the time when the American Air Force was having its first Boeing B-29 converted into a tanker aircraft; the blockade of Berlin by the Russians had commenced on 25 July 1948. Sir Alan Cobham, with his vast experience of conveying and transferring fuel, suggested that Flight Refuelling Ltd was well equipped to airlift fuel into the stricken city, and within

twenty-four hours of the suggestion being made, the Avro Lancastrian tankers that had returned from the North Atlantic trials were put into operation conveying the urgently required fuel. These aircraft originally operated out of Buckeburg, after which they soon moved to Wunstorf, and finally Hamburg. After just over a year Flight Refuelling Ltd had forty-two aircrews carrying out this operation, flying thirty-eight sorties per day with loads of 2,400–2,500 imperial gallons (10,800–11,250 litres) of fuel per flight, eventually having conveyed seven million gallons. This achievement was so successful that some of the aircraft were converted to carry diesel oil.



Lucky Lady II round the world, March 1948



Avro Lancastrian over Berlin

At the end of 1948, the Americans asked Sir Alan whether he could help them with an air-refuelling system for single-seat jet fighters that would not require an operator in the

receiver aircraft. Up to this time all systems had used the 'looped hose' technique. Unlike the bomber or large civil transport aircraft, which had a crew who could assist in the refuelling operation; the fighter pilot required a system where no effort was required of him other than to fly the aircraft. Moreover, as in the Second World War, where the effective use of the fighter proved to be difficult owing to the long distances to be flown, so, too, with today's high rate of fuel consumption by the jet-engined fighter, refuelling in flight became a serious consideration.

In early 1949, Flight Refuelling Ltd proposed a modified 'looped hose' system, which no longer required an operator in the receiver aircraft, thus enabling the pilot to be free to fly the aircraft. Also at this time consideration was being given to the possibilities of ground refuelling the jet aircraft under pressure by designing a ground-service bowser to pump the fuel into the aircraft. Obviously this would enable a quicker turn-round time on the ground. Similarly, in the latest refuelling concept it was also recommended that fuel be pumped from a tanker to a receiver aircraft. Thus this would reduce the time the receiver had to remain in contact, and higher fuel flow rates could be achieved.

The principle of the modified 'looped hose' technique was again based on the 'cross-over' contact method originally developed by Squadron Leader R. Atcherley in the early 1930s, and it was proposed to use this technique for single-seat jet fighters.

The fighter was provided with an automatic reception coupling and windlass situated under the fuselage approximately amidships. To control the equipment the pilot had a three-positioned lever with which he could trail a sinker weight and grapnel attached to a hauling line; or hold it in any desired position ready to haul it in when required. Before refuelling, the fighter pilot moved the lever to the 'TRAIL' position, which permitted the sinker weight and grapnel to trail below and behind his aircraft. At the same

time the tanker trailed a contact line terminating with a sleeved drogue that kept the line near to the horizontal. The fighter would then close in behind and above the tanker and cross from one side to the other, thus causing his hauling line to contact the drogue line of the tanker, which then engaged the grapnel attached to the sinker weight. The tanker then hauled in the contact, disconnected the drogue line and plugged the sinker weight into the refuelling hose nozzle, which was then trailed. The tanker signalled to the fighter pilot that the contact was ready, whereupon he selected 'HAUL'. The refuelling hose was then pulled into the reception coupling, where the nozzle was gripped automatically by the four locking toggles. The fuel was then pumped under pressure into the fighter's tanks until all were filled. At a further signal from the tanker the fighter pilot trailed the refuelling hose and sinker weight, which was then separated by nitrogen pressure from the tanker.

The following figures illustrate this new technique.



Meteor Mk III crossing over



Meteor Mk III crossed over



Meteor Mk III makes contact



Tanker hauling in Meteor Mk III hauling line



Refuelling hose engages Meteor coupling



Meteor Mk III refuelling

The first proposed installation of the equipment in either the Gloster Meteor Mk III or Mk IV single-seat jet fighter is illustrated in [Fig. 36](#).

The windlass and reception coupling were a fixed feature, the latter being located centrally in the fuselage and aft of the tail fairing of the ventral fuel tank. The windlass was powered by a hydraulic motor, which derived its power from the aircraft's hydraulic system and was situated at the bottom and on the starboard side within the fuselage, being secured to the aft face of the rear ninety-gallon fuel-tank bay. The reception coupling was attached to the underside of the fuselage externally, and enclosed within a streamlined fairing. The refuelling hose loads were transmitted through tubular struts from the coupling to strong points within the fuselage structure. Only one fuel pipe was required, which connected the coupling to the top of the ninety-gallon fuel tank at the ground refuelling connection.

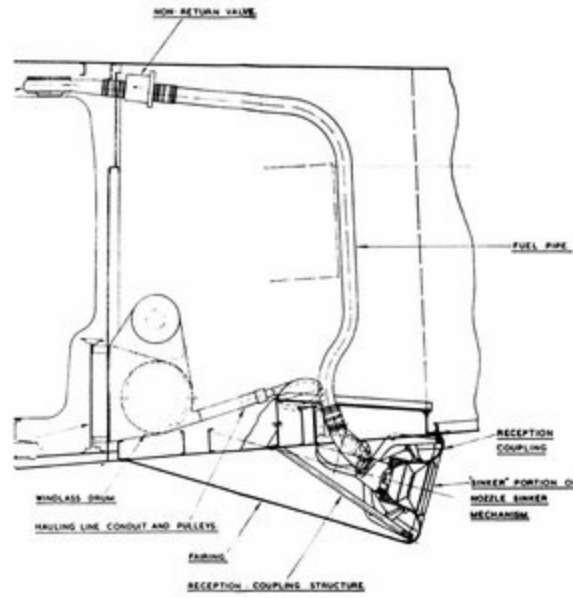


Fig. 36. Meteor windlass and coupling

The second proposal for the Meteor Mk III and Mk IV, which now had the new philosophy of ground-pressure refuelling; was a retractable windlass and reception coupling combined into one unit. This was to be powered by a hydraulic motor being supplied from the aircraft's hydraulic system, together with a hydraulic jack for retraction purposes. The installation was similar to that of the first proposal, in that it was located aft of the ventral fuel tank and at the lower portion of the fuselage internally on its centre line. A single flexible fuel pipe incorporating a non-return valve connected the unit to the aircraft's ground-pressure refuelling gallery.

The windlass and reception coupling comprised a hydraulically driven cable drum capable of storing the necessary length of hauling cable, with a simple transverse gear to ensure that a direct pull was maintained when hauling in the refuelling hose, thereby keeping it on the centre line of the aircraft. A simple claw-clutch was incorporated to control the rotations of the windlass, and provide the means of preventing 'cable-creep' when the

sinker weight had been hauled and stowed. The reception coupling no longer incorporated the four locking toggles that locked the refuelling nozzle in engagement, as this was now achieved by the use of the hydraulic motor running in the stalled condition during the operation, thus maintaining a direct tension on the hauling cable and holding the nozzle in position, at the same time making a fuel-proof joint between it and the coupling. The retraction mechanism was of a simple design, and was effected by a small hydraulic jack located above the pivot point of the unit and secured to a side frame. Retraction stops were arranged so that during the operation the hose loads were transmitted directly to the main structure.

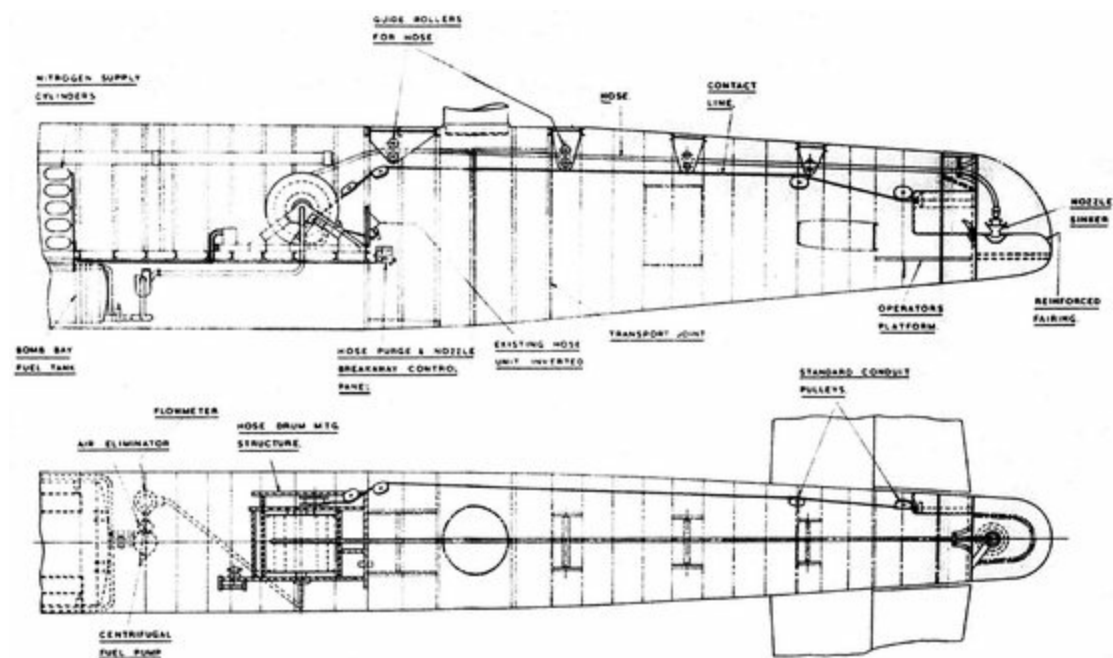
The operation of this now simple unit was similar to the first proposal, but having the one additional selection for retraction.

The tanker aircraft that was proposed for fighter refuelling was the Avro Lancaster bomber, which would make use of the existing well-proved equipment (though repositioned within the aircraft's fuselage), together with a modified contact cable and fuel pumping in lieu of gravity transfer.

In the new concept the only remaining feature of the original 'looped hose' tanker installation was the bomb-bay fuel cargo tanks. The hose-drum unit was moved from the rear of the bomb-bay and relocated above it in an inverted position, together with the contact reel; the operator's control panel was also relocated and was now behind the rear bomb-bay bulkhead. The refuelling hose and contact cable were routed aft, the hose being along the aircraft's fuselage roof and on the centre line via guide rollers; likewise the contact cable, but lower down and on the starboard side of the rear fuselage via standard conduit pulleys. Both terminated where the rear gun turret was located. The rear gun turret was removed for this conversion to allow the hose and contact cable to be trailed, as illustrated in [Fig 37](#), from the aft end of the fuselage. The

hose passed through a flared roller-box system mounted on the rearmost frame of the aircraft, the contact cable with a sleeved drogue passing through a drogue stowage container on the starboard side. The lower portion of the gun turret was replaced by a reinforced fairing, which contained a nozzle and sinker receptacle for securing the hose when not in use and stowed. To enable the operator to view the whole operation, a clearview panel was also mounted on the rearmost frame, together with a line vice to secure the receiver's hauling cable while the hose was being attached to it.

Fig. 37. Proposed Lancaster tanker for fighter refuelling



The fuel system retained the two bomb-bay cargo fuel tanks, these having been divorced from the tanker's fuel system because kerosene was now to be transferred, and not the 100-octane petrol previously used. The rear cargo tank's outlet was connected to a fuel shut-off valve, which in turn connected to the new centrifugal fuel pump, flowmeter and air eliminator, thence to the hose drum. The new pump was

capable of pumping fuel at a rate of 100 imperial gallons (450 litres) per minute, which could be confirmed by the flow indicator deriving its signal from the flowmeter. Nitrogen purging of the hose and fuel system was still employed prior to and after an operation. The system also provided the necessary pressure to break the contact, by blowing the receiver's sinker free from the nozzle after the refuelling sequence and when the receiver pilot had re-trailed the hose.

Although this revised technique employed the well-proved equipment of the original 'looped hose' system, the Air Ministry did not consider that it was merited, and the conversion proposal was abandoned.

However, proposals were still being made concerning an entirely new technique, which was a simpler method of making a contact, with higher fuel flow rates and remote control of the tanker's hose drum. This was a problem that essentially had to be overcome because the United States was still pursuing the need for air refuelling of single-seat jet fighter aircraft.

CHAPTER TWO

The Early Successes, 1949-65

Tarrant Rushton village lies in the folds of the Tarrant river valley in Dorset, situated 10 miles north of the ancient market town of Wimborne Minster and adjacent to the Iron Age hill fort of Badbury Rings. Above the village is an escarpment which ends as a small cliff, and it was upon the plateau above that Tarrant Rushton airfield was built in 1943. At once it began to play a historically significant role in the Second World War, being the launching pad for corps of the Airborne Division in Normandy in 1944. Not only that, but the Special Operations Executive sent its agents from it for undercover activities with the European freedom fighters.

It seems fitting, therefore, that such a location should have become the auspicious cradling of a New Age of enhanced aviation. And it is also fitting—a kind of destiny—that one particular veteran of an earlier War in the Air should settle here to nurture a daring concept with the discipline of a self-taught technology.

Stimulated by the American pressures for in-flight-refuelling fighter aircraft, an entirely new departure from the current orthodoxy described in Chapter One was instituted at Tarrant Rushton in April 1949. This was ostensibly to comply with the American insistence on a means of contact between tanker and receiver that must be as near robotic as possible. Unlike the bomber pilot with his multiple crew, the fighter pilot was always fully preoccupied with the operation of flying his aircraft, and so refuelling

needed to be as nearly automatic as practicable.

To achieve this the tanker aircraft was fitted with a refuelling hose to be trailed from the fuselage. The hose was equipped at the trailing end with a reception coupling and a hollow cone acting as a drogue, the base of the cone facing aft. The hose was stowed in the tanker on a hose drum unit designed to maintain a constant tension during the operation, thereby avoiding any slackness. The fixed end was connected to a sealed, rotating, fuel joint within the hose drum.



Tarrant Rushton airfield,
Dorset, 1944



Tarrant Rushton
airfield, 1950s

As in the previous fighter refuelling system, the fuel would be drawn from the cargo fuel-tanks by a lightweight fuel pump specially designed to ensure maximum rates of flow.

The fighter (receiver) was fitted with a rigid probe having an inner fuel pipe connected to a nozzle at the forward end, and at the rear to the aircraft's ground-pressure refuelling gallery, the latter in turn supplying the aircraft's fuel-tanks,

each tank having a shut-off valve.

At the commencement of the refuelling operation the tanker trailed the hose to a fully trailed position. The fighter then approached the tanker slightly below and astern, the pilot flying into such a position that the probe on the nose of the aircraft could engage the conical drogue at the end of the hose. The fighter would then advance a few feet, which had the effect of centralizing the conical drogue on the probe, and overriding the air drag on it, the slack hose being taken up by the tanker's hose-drum unit. In this position the conical drogue was held firmly against the fighter's probe by the air drag. At the same time locking toggles contained within the reception coupling engaged an annular groove on the nozzle, making a leak-proof joint between the two. The locking toggles within the coupling were so loaded that the connection between it and the nozzle would maintain a leak-proof joint up to a delivery pressure of 60 psi, yet permit easy withdrawal when the fighter pilot wished to fall back and break contact.

As the fighter engaged the refuelling hose and advanced on the tanker, automatic retraction of the slack hose onto the drum was used to open the main fuel valve in the tanker, thus starting the flow of fuel through the hose to the probe and via the fighter's fuel gallery into its fuel-tanks. In the formation position, there would be space fore and aft to permit the fighter pilot to advance, having as much as twenty-feet latitude between his aircraft and the tanker.

This technique became known as the 'probe and drogue' system, vastly different from the original 'looped hose', the receiver having ample manoeuvring space while the tanker flew straight and level throughout the operation.

The originators of the 'probe and drogue' system, whose names appear on the Letters Patent, were Sir Alan John Cobham, Mr C.H. Latimer-Needham, Mr C.H. Smith, and Mr P.S. MacGregor (to whom this book is dedicated). Though

the system was of a simple design there were various problems that had to be overcome in the early stages, the principal one being the behaviour of the refuelling hose and drogue in free flight. Initial trials of the drogue's trailing characteristics were carried out by trailing a parachute-type drogue from the wingtip of a Lancastrian aircraft, the length of trail being determined by the control of a manually operated winch. These trials began in February 1949, and made use of Lancastrian G-AKDO, which was flying in and out of Berlin during the Berlin Airlift. This aircraft was fitted with a short strut beneath one of its wingtips, from which a drogue attached to a cable was trailed. The results indicated that the drogue flew steadily, though rotating about its axis, and would on occasions make rotating movements out of the axis. These tests appeared to be promising. A metal conical drogue of 129 degrees included angle, having a diameter of 26 inches (660 mm), was substituted. On being trailed over a short distance, the drogue broke free due to rotation and twisting of the cable. Nevertheless a further metal drogue having a 90-degree included angle with the same diameter was tried, but this also incorporated a thrust bearing within its attachment to the cable, thereby overcoming the effect of the drogue's rotation twisting the cable. On a short trail length this was found to be very stable, but when the trail length was increased, rotation about its axis again occurred. The conclusion drawn from these experiments was that the drogue was inherently stable when trailed from its apex, but that erratic behaviour was due to the wingtip vortex, which encouraged the rotations. To overcome this problem the 90-degree drogue, together with a short length of hose, was trailed from the rear gun turret of the Lancastrian. This combination was shown to be stable throughout the speed ranges of the aircraft, the hose and drogue flying at an angle of 5 degrees below the horizontal. In March 1949 one of the original Tiger Force receivers (ND.648) had this hose and drogue installed to investigate whether a Gloster Meteor could make a contact on the drogue. The Meteor, from

A&AEE Boscombe Down, was flown in formation with the tanker. The pilot of the Meteor reported that the drogue was in disturbed air and made formatting difficult, but at a position some 10 feet (3 metres) above and below the drogue it was satisfactory. He also formatted on the aircraft's wingtip, and found that the wingtip vortices made it almost impossible to maintain position. He also found that by using his dive-brakes and flaps he could maintain formation with adequate control of the aircraft down to 160 knots indicated airspeed. One of the important problems of the new system had now been virtually overcome. But the outstanding problem was the response of the hose drum when a contact was made. This was preventing the refuelling hose from whipping due to any slackness. MacGregor came up with the idea of a spring-loaded hose drum, together with other 'stored-energy' concepts. Eventually it was decided to incorporate a fluid coupling in the drive system between the hose drum and driving motor, thus providing the capability of varying the torque output at the drum.

The basic principle of the 'probe and drogue' system is illustrated in [Fig 38](#), which shows the simplicity of the design, the main feature being the introduction of the 'fluid drive coupling' within the hose drum's drive system, where the rotational force (torque) could be varied. Its use was such that during the operation a constant 'wind-in' torque was applied to the refuelling hose and drogue. When these were initially trailed, the air-drag load of the two components was greater than that of the wind-in torque, thus allowing the fluid drive coupling to slip, but controlling the speed of the trailing sequence.

At the fully trailed position of the hose and drogue, a hose-drum brake would be applied, the hose and drogue remaining at this position while the fluid drive still applied a wind-in torque. However, when the receiver made a contact and engaged the reception coupling, the air drag on the drogue was removed from the end of the refuelling hose, the

drag now being applied on the nose of the receiver aircraft. This then left only the drag and weight of the refuelling hose to be overcome by the hose-drum unit, sufficient torque being available to prevent any slack being in the hose when the receiver pushed forwards, thus maintaining a constant tension.

While the design and development of the drogue and hose drum response were in progress, consideration was being given to the design of the reception coupling, and the receiver's probe nozzle. The original concept of these was derived from the previous knowledge and experience of the 'looped hose' equipment. The design of the coupling provided a small entry load but a higher one to disconnect, the reason for this being to prevent inadvertent disconnections occurring should a high fuel surge arise, maintaining the locking load. This was achieved by the use of spring-loaded toggle arms with rollers.

The first items of this new refuelling equipment were designated as the Mk I probe nozzle and the Mk I reception coupling. These initially provided an entry load of 5 lb for the nozzle to engage the coupling, with a disconnect load of 180 lb.

The original concept for the tanker was for the hose and drogue to be trailed from each wingtip of the aircraft, thus enabling two aircraft to refuel at once. The hose drum was to be capable of storing 40 feet of 1½-inch bore hose wound on to a Catherine-wheel-type drum, which when installed would lie flat within the wing's structure. This concept was abandoned due to the evidence acquired from the earlier trials with the various drogues, which showed that the vortices enticed too much rotational movement.

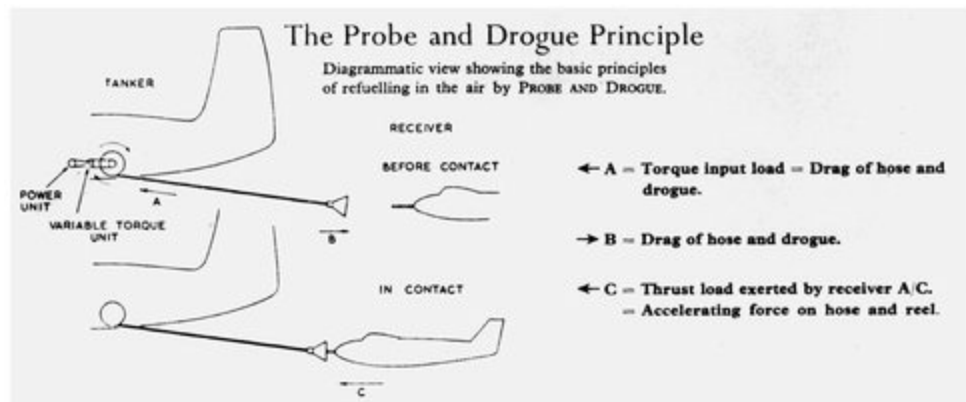
It was therefore decided that one of the original Tiger Force tankers (PB.972), which had been used earlier for the civil long-distance trials, could be adapted for the forthcoming trials with a Gloster Meteor as a receiver. The

hose and drogue would be trailed from the bomb-bay of the tanker using the existing Mk V 'looped hose' hose drum suitably modified. Although the hose-drum unit was driven by a hydraulic motor, a system could be devised where the output torque could be varied similar to that of the fluid drive coupling. This adaption was achieved by introducing an adjustable pressure-relief valve in series with a shut-off valve across the motor's hydraulic supply line. To enable the receiver to make a fast contact, the gear ratio of the drum's drive system was changed, and an increase in the drum's diameter provided a hose response of 10 feet per second, which was adequate to ensure that no slack hose occurred when a contact was made.

Unfortunately, as the 'probe and drogue' system was on the point of becoming a workable system, the Ministry of Supply informed Flight Refuelling Ltd that the contract for the two Lancaster aircraft PB.972 and ND.648 was for civil operations only. This was due to expire on 31 March 1949, and any further work carried out after that date would be considered 'Private Venture'. This was a serious setback to the plans being made to demonstrate the new system, bearing in mind also that the United States of America was still pressing for air refuelling of their single-seat jet fighters. After much discussion, and requesting an extension to be made to the contract, the Ministry of Supply responded stating that they did not hold out much hope for such an extension unless operational use was requested by the Royal Air Force or British Overseas Airways. At the time neither was interested. Nevertheless, eventually Flight Refuelling Ltd purchased the two aircraft from the Ministry of Supply, which in the sale agreement imposed limitations on their use and operating distance from their home airfield, and stipulated that they could only be flown under B-Class conditions. The two aircraft were then re-registered in May 1949-Lancaster PB.972 to G-33-2, and ND.648 TO G-33-1 - even though during the crisis of the two aircraft negotiations were being made for the hire of a Gloster Meteor Mk III to

act as a receiver. These were successfully concluded, and the aircraft was eventually allocated, designated as EE.397. On its arrival it was immediately modified to incorporate a fabricated probe structure mounted from the aircraft's front bulkhead and nosewheel undercarriage structure, the probe protruding some 39 inches (1 metre) forward of the nose fairing, with the probe nozzle tip being visible to the pilot. The probe also incorporated a manual release system whereby it could be jettisoned should it become impossible to make a disconnect. Although the Mk 1 probe nozzle was fitted, no fuel system was installed, as the early trials were to be dry, proving the practicability of making contact, together with the formation positions.

Fig. 38. Principle of probe and drogue refuelling system





Gloster Meteor Mk III EE.397 receiver

The Lancaster tanker (G-33-2) now had the MkV hose-drum unit modified, together with the capability of carry 65 feet (20 metres) of 2.01-inch (53 mm) bore refuelling hose, and a U-shaped structure added beneath its fuselage to hold the drogue in position once it had been wound in and stowed.

Still in its Royal Air Force markings, G-33-2 made an initial handling flight, piloted by T.C. Marks on 22 April 1949, and on the 23rd the first probe and drogue contact was attempted. Unfortunately, due to a burst hydraulic pipe, the flight had to be aborted, and the first contact was made the following day, 24 April, when P.R. Hornidge made three successful contacts. He then landed and refuelled and made a further flight, during which he repeatedly made numerous contacts.

During these trials an American Air Force delegation visited Tarrant Rushton airfield, and on 27 April they witnessed a demonstration of the probe and drogue system from the air in two Lancastrian aircraft. After the demonstration they commented that they were very impressed with the new system, and that they would consider ways in which to use it.

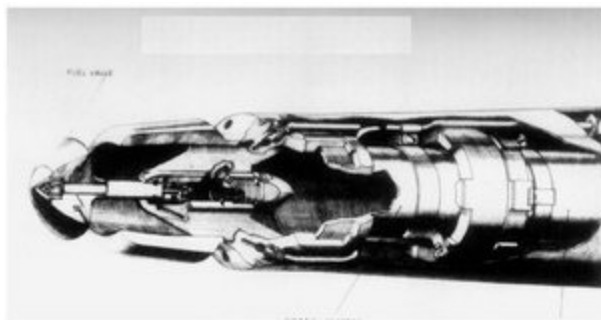
Even though the initial flight trials and the American demonstration were a great success, these early trials were not without problems. It was found necessary to increase the disconnect load between the reception coupling and nozzle, and there was a tendency for the 90-degree drogue to hang up on the probe nozzle, which was cured by introducing a modified drogue with an included angle of 60 degrees.

A further demonstration of the Lancaster and Meteor combination occurred on 18 May, in the presence of representatives of the Air Staff and Fighter Command, together with other interested personnel. Among those present was Group Captain S.R. Ubee, of the Technical Requirements Branch, who had also been involved in the early '30s with the Royal Aircraft Establishment's trials of flight refuelling.

On 1 June another demonstration took place, when a pilot from A&AEE Boscombe Down flew the Meteor. He also made successful contacts, stating that any fighter pilot could do the same. On 21 June yet another demonstration was made, this time in front of the Air Officer Commanding Fighter Command, the Meteor being flown by a service pilot. He also made successful contacts and confirmed the comments made by the Boscombe Down pilot. The AOC Fighter Command added that he was convinced that the new technique was practicable and would consider it for future use.

Modification of the Meteor Mk III aircraft to permit the transfer of fuel was now a matter of some urgency, as the United States Army Air Force representatives were expecting to observe a demonstration of wet contacts in the forthcoming July. However, before using fuel for wet contacts, it was necessary to prove the probe nozzle and reception coupling wet in flight. To enable this to be carried out safely, a water tank was connected to the hose-drum unit in Lancaster G-33-2, with the refuelling hose primed with water, and the fuel connection behind the receiver's probe nozzle being blanked. On the test flight with this

configuration, the nozzle and coupling were found to be satisfactory when engaged, but when a disconnect was made a large splash of water occurred. During this first wet contact it was soon realized in the tanker that insufficient allowance had been made for the contraction of the hose when the receiver pushed the hose back onto the hose drum. As a consequence the flight-test observer was suddenly given an involuntary shower. The disconnect problem had now to be overcome quickly, and it was decided to install a new probe nozzle having an integral shut-off valve to be controlled by the receiver pilot. The concept of this new nozzle was for a contact to be made with the nozzle valve shut; on making a successful contact and engaging the coupling, the pilot would then operate a switch located on his control column, which in turn would open the valve within the coupling. Before making a disconnect the pilot would select the valve shut, the coupling's valve shutting automatically, thus preventing any splash. The new probe nozzle incorporated a valve that was actuated by a small hydraulic cylinder contained within the nozzle, the hydraulic pressure being supplied from the aircraft's hydraulic system via an electrically operated control valve.



Gloster Meteor Mk II probe nozzle

The Lancaster G-33-2 was also modified to introduce a wet fuel system, the fuel being supplied from the bomb-bay cargo tanks and pumped by five small booster fuel

pumps. These provided a combined output of 100 imperial gallons (450 litres). At the same time further improvements were incorporated in the tanker's system. A combined fuel and vent valve was introduced between the fuel pumps and hose-drum unit. The operation of this valve was derived from the rotation of the hose drum, which provided a signal at a defined position to open and close it. When the receiver made a contact it was necessary to push the hose in, the slack hose being wound in automatically. After 3 feet of hose had been wound in, the fuel/vent valve would be signalled to open the fuel valve and close the vent; upon the receiver breaking contact the reverse sequence occurred. The necessity for the vent valve was because when the receiver made contact, pushing the hose in, it contracted and displaced a quantity of fuel, and the valve permitted this excess to be returned to the aircraft's fuel system via the venting system.

The second improvement was the introduction of 'Contact Lights', these being located so that the receiver pilot could clearly see them; their purpose was to inform him of the state of the tanker. Accordingly two illuminated coloured lights were installed, these being 'AMBER' and 'GREEN'. The AMBER indicated that the refuelling hose was trailed and ready for a contact, and the GREEN that the fuel was being transferred. The AMBER was illuminated via switching operated by the rotation of the hose drum; and the GREEN was illuminated via the operation of the fuel/vent valve, once the valve had been opened by the 3 feet of hose being wound back onto the hose drum.

All the modifications proved to be satisfactory in actual operation, and on 25 July 1949 the first fuel transfer with the probe and drogue system was successfully achieved. The numerous demonstrations given of the system, together with the reports, encouraged support for further development. To enhance this, Flight Refuelling Ltd decided to demonstrate the practicability of an endurance flight of a jet fighter, using the Meteor Mk III EE.397.

On 7 August 1949 at 05.20 hours the Meteor took off from Tarrant Rushton airfield, being flown by P.R. Hornidge, who flew a continuous circuit over the south-west of England; while the Lancaster G-33-2, flown by T.C. Marks, maintained a circuit round the Isle of Wight, making a rendezvous off the Needles to refuel. The contact was made at an altitude of 6,000 feet (1,846 metres), and at a speed of 190 mph. Ten such contacts were carried out, 2,352 imperial gallons (10,584 litres) of fuel being transferred, which enabled the Meteor to travel 3,100 miles, finally touching down at Tarrant Rushton after remaining airborne for 12 hours 3 minutes. During this great achievement the Lancaster tanker had to land twice to replenish its fuel tanks, together with the cargo tanks, which contained kerosene. During the last three hours of the flight, rain and poor visibility necessitated several contacts being made in cloud.

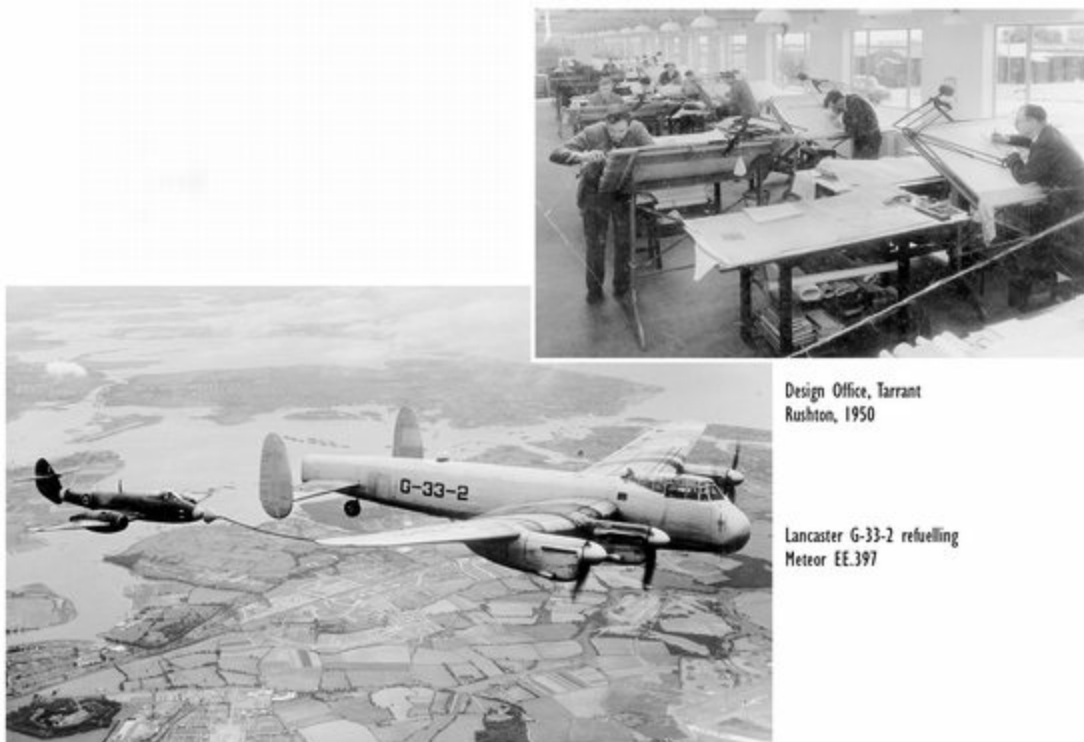
Later, Hornidge gave his impressions of the flight, which was recognized as an official record for a jet fighter: 'It was a bit boring ... I took a book with me to read, but the weather got so bad that I had to keep my eyes on the instruments most of the time. I really got fed up after ten hours, but the sight of the tanker coming to refuel helped to relieve the monotony.' The Meteor is shown below, refuelling over Portchester Harbour, Hampshire.

On landing, the Meteor was encircled by a galaxy of pressmen, all eager to see Hornidge, and the event received worldwide publicity, much to the delight of Sir Alan Cobham. In addition to this very welcome publicity the flight considerably impressed the Air Ministry.

The first public demonstration of the probe and drogue system took place at the Royal Air Force station at Beaulieu in Hampshire, in September 1949, and was followed by another at the Royal Aircraft Establishment, Farnborough, before a gathering of foreign and aviation VIPs.

The United States of America was the forerunner in

placing an order on Flight Refuelling Ltd in the autumn of 1949. This entailed the conversion of two B-29 Superfortress bombers into receivers, one B-29 into a single-point tanker, another into a three-point tanker, and two Republic F.84E Thunderjet single-seat fighters into receivers. This order gave an enormous boost to the philosophy of in-flight refuelling. When senior members of the staff were discussing the task and how best it should be carried out and what job number should be used, Sir Alan replied, 'There is only one number for this contract and that is 4711, as it is the sweetest number that I know.' He was, of course, referring to the famous perfume of the time.



Design Office, Tarrant
Rushton, 1950

Lancaster G-33-2 refuelling
Meteor EE.397

Prior to this order, development of the system was well under way. A new hose-drum unit, designated as the Mk VII, was designed specifically for the new system and was to be installed in Lancaster G-33-2. The hybrid MkV hose-drum unit was to be removed and installed in Lancaster G-33-1, which still had 'looped hose' receiver equipment fitted. The

aircraft had been involved in formation trials with large aircraft, and was now to become the second tanker for the development programme. From the early concept of February 1949 it was apparent how quickly design problems could be resolved. Flight Refuelling Ltd was now extremely busy, designing new hose-drum units for the American aircraft, together with the development and final installations.

Also at this time the Royal Air Force was again seriously considering the conversion of an Avro Lincoln bomber into a tanker and some of its Gloster Meteor aircraft into receivers. With all these projects coming to fruition Sir Alan enlisted the assistance of Arthur Hagg as a consultant for the various installations. Hagg had led the design team on the Airspeed Ambassador airliner, and was very interested in these new projects. During this period of intensified work Flight Refuelling Ltd was dispersed between St Nicholas, Littlehampton, in Sussex, and Tarrant Rushton in Dorset. To centralize the company, plans were being considered to move all of the staff to Tarrant Rushton, and this move did come about in early 1950, together with an extension to the design office.

It was at the beginning of this large influx of design and development that the author joined the company, and was to be involved in one way or another in all the in-flight-refuelling projects until November 1988.

The Boeing B-29 Superfortress bomber's conversion into a three-point tanker was the largest single project, and the first of its type, requiring two types of hose-drum unit capable of being remotely controlled, with one positioned in the rear fuselage, and another at each wingtip, together with new fuel pumps to provide a higher rate of fuel flow, coupled to a fuel system isolated from the aircraft's system.

The aircraft was given the American designation of YBK-29T, indicating that it was a tanker, and capable of refuelling

three aircraft simultaneously. This is shown below, with two Royal Air Force Gloster Meteor Mk VIIIs, WA.826 and WA.829, receiving fuel from the wingtip hose-drum units, and a Gloster Meteor Mk IV, VZ.389, from the fuselage hose-drum unit.



Boeing B-29 three-point tanker refuelling three RAF Gloster Meteors

The Boeing B-29 single-point tanker employed the Mk VII Series 1 retractable hose-drum unit, which was a development of the Mk VII mentioned earlier.

The hose-drum unit was located in the rear fuselage of the aircraft, and at the same position as the Mk IX unit of the three-point tanker, also making use of the keyhole slot previously used for the 'looped hose' system. This unit, however, was manually operated, the operator being located in the unpressurized portion of the rear fuselage. Similar to the three-point tanks, the two bomb-bay fuel-tanks were isolated from the main aircraft fuel system. The system permitted the transfer of fuel at a flow rate of 208 imperial (250 US) gallons per minute to a receiver aircraft.



Boeing B-29 Superfortress single-point tanker

The Republic F.84E. Thunderjet receiver conversion was the first single-seat jet fighter to be in-flight refuelled in service, as shown above being refuelled from a Royal Air Force Avro Lincoln tanker in 1951.



Avro Lincoln refuelling F.84 Thunderjet

It was capable with the new refuelling system of receiving 759 imperial (912 US) gallons of fuel, as well as being able to refuel all of its fuel-tanks in one refuelling operation.

The refuelling probe installation on this aircraft was located on the aircraft's port wing, which was connected by

the new refuelling fuel system to all the aircraft's fuel-tanks.

Similarly, two Boeing B-29 Superfortress aircraft were converted to receivers, one of which was specially designed to receive high flow rates of fuel, the other a low rate of flow. One such aircraft is shown below, refuelling from a Boeing B-29 Superfortress tanker off the Dorset coast in 1950.

Both aircraft were capable of receiving 4,416 imperial (5,298 US) gallons of fuel. Thus the two inboard fuel-tanks of the port and starboard wings, together with the rear bomb-bay tank, could be refuelled in one operation.



Superfortress tanker refuelling Superfortress receiver

The low-rate-of-flow aircraft also had the facility for ground-pressure refuelling incorporated, using the new main probe fuel line for the purpose.

The high-rate-of-flow aircraft did not have the ground-pressure refuelling, but it did incorporate in the new fuel system a progressive fuel-shut-off mechanism added to each of the fuel-tank's refuelling shut-off valves. The incorporation of this mechanism prevented high-pressure fuel surges occurring in the fuel system when the fuel-tank's fuel supply was shut-off.

After all the previous years of trials, which had proved to be successful but without any in-flight refuelled service being achieved, from the autumn of 1949 it was a period of intensified design, manufacturing and installation of the new equipment for the American Air Force. Up to this time no publicity had been received, because of the secrecy of the application to American service aircraft. The Royal Air Force now took a further interest in this latest technique of air refuelling. Flight Refuelling Ltd had put forward proposals for an Avro Lincoln tanker, together with a Gloster Meteor Mk IV receiver, to demonstrate the advantages that could be gained in deploying fighter aircraft. In early 1950 an Avro Lincoln Mk II (RA.657) and a Gloster Meteor Mk IV (VZ.389) were allotted to the company for conversion, together with a programme of trials. It is important that mention of the Lincoln tanker is made here, though its description is later, on account of the following epic achievement by the American Air Force, where the use of the Lincoln became necessary.

The earlier text recalls that it was the Americans who encouraged Sir Alan Cobham to conceive a simpler system than the well-known 'looped hose' system of refuelling for the single-seat jet fighter in the air. The first of these were the two Republic F.84E Thunderjet fighters converted at Tarrant Rushton. They first flew in this configuration in August 1950, using the Boeing B-29 Superfortress single-point tanker and Flight Refuelling Ltd's Lancaster G-33-2 for their initial flight testing. On completion of these, it was planned to fly them non-stop from the United Kingdom to the United States of America across the North Atlantic. Prior to this planned epic flight, and to prove the reliability of the new equipment in both tankers and receivers, a triangular course around the United Kingdom was flown using the B-29 and Lincoln tankers. However, an equipment problem arose in the Lancaster tanker G-33-2, which necessitated the Lincoln getting airborne as quickly as possible to save the day, and it eventually managed to rendezvous with the

Thunderjets and refuel them.

On 22 September 1950 the system was dramatically demonstrated when Colonels D. Schilling and R. Ritchie flew the two Thunderjets non-stop from Manston, in Kent, to Limestone, Maine, USA. This flight was supported by the Flight Refuelling Ltd Lancaster tanker G-33-2 based at Prestwick, Scotland, the Lincoln tanker RA.657 at Keflavik, Iceland, and the Boeing B-29 Superfortress single-point tanker at Bluie West 1, Canada. The Thunderjets made successful contacts with the tankers out of Prestwick and Keflavik, and continued to meet the tanker out of Bluie West 1. On meeting the tanker, Schilling made a successful contact, but Ritchie unfortunately bent his aircraft's probe fuel valve on making contact, which implied that he had inadvertently opened the valve too early. The valve being damaged meant that he could not make a further contact and replenish his tanks. His only option was to put the aircraft on a heading towards the coast of Canada and bale out, also transmitting a Mayday call. He did eventually bale out of the aircraft when the fuel state was at a low level, and landed some thirty miles from Goose Bay, where he was soon picked up by a rescuing helicopter. Schilling, however, having been replenished with fuel, continued his flight, eventually landing at Limestone, Maine.

This particular flight put the probe and drogue system on the map so far as the Americans were concerned, proving that it was feasible to fly single-seat jet fighters over long distances, and to rendezvous with the tanker. The American Air Force increased its interest, and commenced to fit its single-seat jet fighters with probes. Also at this time, Flight Refuelling Ltd evaluated the positioning of probes on various aircraft, either the nose or wing, and fitting them directly to under-wing drop tanks, the latter being the simplest and quickest conversion. The American Air Force adopted the latter method for the F.86E Sabre fighter.



F.86E Sabre drop-tank probes

The original Boeing B-29 Superfortress three-point tanker played a major part in flights across the Central Atlantic and the Pacific oceans, and over long distances in South-East Asia. When the Korean conflict started, the system was tested under battle conditions, both the F.86E Sabre and F.84E Thunderjet aircraft being successfully used. One Thunderjet flown by Colonel Harry Doris was able to carry out six strikes in one sortie, having refuelled from a tanker seven times, allowing him to remain airborne for a staggering 14 hours 5 minutes. During these operations the F.86E Sabres reverted to Sir Alan's original concept of taking off with a light fuel load, since the Korean airstrips were too short for a full load take-off, and the use of the JATO rockets to assist them would create impenetrable dust clouds. The aircraft, having taken off with a light fuel load, were topped up immediately overhead before proceeding to their various targets.

Flight Refuelling Incorporated had been established at Danbury, Connecticut, USA, to support the increased American interest, but later moved to larger facilities at Friendship Airport, Baltimore. However, due to the strict American security regulations imposed on military equipment, Sir Alan was forced to resign his seat on the board of that company. Nevertheless the company continued in the business of supporting the later Boeing B-29 and B-50 tankers that were converted to the system. Mr C.H. Smith, one of the originators of the new system, and the chief

designer of Flight Refuelling Ltd, left the company and joined the American concern. His place was taken by Mr A.W. Goodliffe, who had been involved in the early development of the probe and drogue system with Peter MacGregor. He later became the technical director of Flight Refuelling Ltd, and Peter MacGregor the chief designer.

Due to the American Air Force's large involvement in the Korean theatre, tanker aircraft with the new system were urgently needed to maintain the long-distance strikes being carried out, as well as the ferrying of aircraft to that region. To overcome this situation six Boeing B-29M Superfortress 'looped hose' tankers were sent to Tarrant Rushton for emergency adaptation to the probe and drogue system.

Although the new system was received with great enthusiasm by the Americans, and even though it had been publicly demonstrated in September 1949 with Lancaster G-33-2 and Meteor Mk III, EE.397, and later at the Society of British Aircraft Constructors Farnborough Airshow with the Lincoln RA.657 and Meteor Mk IV VZ.389, none of the American conversions were demonstrated publicly owing to the tight American security. However, I can recall on the public day of Saturday, when I was on the company's stand with Peter Proctor, the then sales manager, and an American Air Force representative, two young boys came to the stand with their father. One of the boys commented, 'This is the firm what refuels them in the air three at a time, Dad.' Peter and I just looked on, making no comment, then came the final statement: 'We seed 'em doing it over Studland Bay near Poole in the summer, the tanker was a Superfortress refuelling three Meteors.' The three of us just looked and shrugged our shoulders: so much for American security!

While the major design and manufacturing activity was being carried out for the Americans in 1950, the British Ministry of Supply placed an order on the company for the conversion of one Avro Lincoln Mk II bomber, RA.657, into a single-point tanker, and one Gloster Meteor Mk IV, VZ.389,

into a receiver. These conversions were, as previously mentioned, to evaluate the advantages of the new aerial refuelling technique. Shortly after the two aircraft were allotted to the company, a flight trial to evaluate the Lincoln's performance was carried out. The requirement of this was to prove whether it could achieve an airspeed of 160 knots at an altitude of 25,000 feet, this being the airspeed required at the time to air refuel all British military aircraft. At the same time the Meteor evaluated the formatting positions behind the aircraft, not only with the Lincoln but also with Lancaster G-33-2. The result of the Lincoln's trials showed that it could not achieve the required airspeed at 25,000 feet but that it was achievable at 22,000 feet, which was accepted for the purpose of the evaluation. The Meteor's trials were more successful, having no problems with either aircraft.

The conversion of the Lincoln (Fig 39) utilized the aircraft's bomb-bay for the installation of two 600-imperial-gallon (2,700 litres) cargo fuel-tanks and the fuel transfer system, together with tapping No. 1 port inner wing tank. containing a further 585 imperial gallons (2,633 litres) of fuel, thereby providing a total 1,785 imperial gallons (8,033 litres) of transferable fuel at a flow rate of 200 imperial gallons (900 litres) per minute. The hose-drum unit was located aft of the aircraft's bomb-bay, where the radar scanner was originally installed.

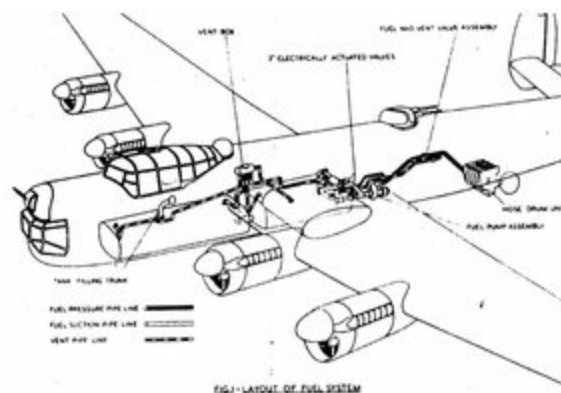


Fig. 39. Avro Lincoln tanker RA.657

As the Lincoln and Meteor were on loan for six months only for evaluation, demonstration and further development of the system also together with a delay for completion, an extension to the contract was requested. This also included a request that the aircraft be allowed to demonstrate the technique with the de Havilland Comet airliner, and that the Meteor should carry out simultaneous refuelling with the Boeing B-29 Superfortress three-point tanker and the two Republic F.84E Thunderjets.

Some reluctance to this came from the Ministry of Supply, as the flying hours would be extra to those already agreed. However, the whole programme was eventually given approval. Even though the two aircraft were allowed to give demonstrations, no official requirement for the probe and drogue system to enter service with the Royal Air Force had been raised. Nevertheless, receiver probe installations were examined for the Gloster NF.11, the Gloster Javelin, Hawker Hunter, and the de Havilland 110 Sea Vixen. During this period the technique of the probe and drogue system was being studied by the Science 3 Department of the Air Ministry and Fighter Command. To assist them, Latimer-Needham wrote a paper on Flight Refuelling as applied to fighter aircraft on a standing patrol. He examined the requirements (both unrefuelled and refuelled) for the mounting of a 24-hour standing patrol at low altitude, covering 1,200 miles of coastline, deploying the Meteor Mk IV fighter. The lines of patrol varied from 30 miles to 200 miles from the coast, utilizing four aircraft to cover 400 miles. The result of this showed that when the patrol was extended from the coast, the fighter savings exceeded the tanker effort. If, however, it was extended to 150 miles from the coast, the use of unrefuelled aircraft indicated that it would be impossible to maintain the patrol. Nevertheless, when air refuelled, the patrol could operate 200 miles from

the coastline, and when using the technique, the number of sorties could be reduced, so that savings in manpower, maintenance and fuel would be achieved. The conclusions that Latimer-Needham came to were accepted by the Scientific Department of the Air Ministry.

Meanwhile, Lincoln RA.657 and Meteor VZ.389 were involved in the initial flight testing, the early parts of which were not very successful when problems occurred with the Lincoln's hose-drum unit. The problem was that when the Meteor made a contact, followed by pushing the refuelling hose to the refuelling position, the hose-drum unit did not provide sufficient hose wind in torque for the response. The hose therefore ran off the hose drum, causing it to loop beneath the Meteor's nose, resulting in a severe whipping action that removed the Meteor's probe nozzle. The problem was soon overcome, and successful contacts were made, together with the transfer of fuel.

Then there followed a flight trial to refuel the de Havilland Comet airliner from the Lincoln, the airliner having a dummy dry probe fitted to its nose. However, during the preliminary study for the trials some concern was shown that with the existing length of refuelling hose the Comet might be too close to the Lincoln once a contact had been made. This concern was overcome by the incorporation of a longer length of refuelling hose, which was in addition to the maximum capacity of the hose drum. The additional length was temporarily secured to the underside of the Lincoln's rear fuselage, and was released prior to it being trailed from the hose drum.

The Lincoln was piloted by Mr T.C. Marks, and the Comet by Group Captain J. Cunningham, the chief test pilot of de Havilland Aircraft, with Mr P. Hornidge in the second seat. Several contacts were successfully made, but the proposal to air refuel the Comet was abandoned.

Following a visit to Tarrant Rushton by two Air Staff

officers of the Royal Air Force, the question of the future for air refuelling was discussed at an Air Council meeting. It was agreed that further development of the probe and drogue system should be sponsored by the Royal Air Force, which could be achieved by the conversion of a squadron of Gloster Meteor Mk IVs into receivers. To further this it was also proposed to request Fighter Command to carry out flight trials under simulated war conditions, using tankers operated by Flight Refuelling Ltd.

Both Fighter Command and the Air Staff were now favouring official trials, whereupon Flight Refuelling Ltd was invited to submit cost estimates for the conversion of either eight or sixteen Gloster Meteor Mk IV aircraft into receivers, together with the operating costs for the Lincoln RA.657 and Lancaster G-33-2 tankers. However, both the Lancaster tankers G-33-1 and G-33-2 were company owned with a B-Class limitation, restricting their radius of operation. These two aircraft were also involved in continuous development work, and it would therefore be impossible to use them in the trials for any length of time. Alternative tanker conversions were investigated, which included the Washington bomber (Boeing B-29 in service with the RAF), the Avro Lancastrian from earlier trials, and the Handley Page Hastings. The company thought that the ideal solution for the tanker would be to convert two further Lincoln aircraft, and with this in mind the necessary work by the company was put in hand without an official order.

Meanwhile, an order was placed on the Gloster Aircraft Company for the conversion of sixteen Meteor Mk VIIIs to receivers, this being subcontracted to Flight Refuelling Ltd. On delivery of the first six aircraft, some concern was shown, as the fuel system differed from that of the Mk IV. After a design investigation it was found that a trial installation was unnecessary. The aircraft to be converted came from No. 245 Squadron, based at Horsham St Faith, Norfolk, the first being WA.830, followed by WA.823, WA.826, WA.827,

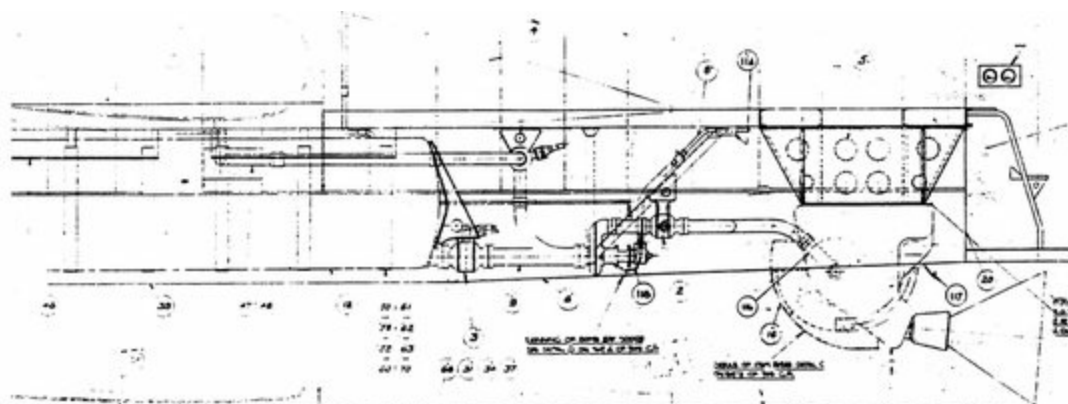
WA.828, WA. 829, WA.832, WA.834, WA.836, WA.837, WA.936, WA.938, WA.941, WA.946 and WA.952.

Later, three more MkVIII aircraft, VZ.476, VZ.543 and VZ.528, were converted, but these were used experimentally and not issued to a squadron.

The probe installation on these aircraft was similar to that of the previous conversions, and the clearance conference to accept the design was held on 26 January 1951. The first flight trial with WA.830 was carried out with the Lincoln RA.657 on 16 February 1951. Two of the Meteors, WA.826 and WA.829, were temporarily detached to Tarrant Rushton for six days in July 1951 to participate in demonstrations of simultaneous refuelling. Together with Meteor VZ.389, they refuelled from the Boeing YKB-29T three-point tanker previously mentioned and shown on page 50.

After other tanker conversions for the trial in February 1951 had been investigated, an order was placed on Flight Refuelling Ltd for the conversion of two further Avro Lincoln Mk 11 bombers into tankers, these being RE.293, and SX.993. The installation of the refuelling equipment differed from that of RA.657 in that the hose-drum unit was located in the aircraft's bomb-bay, together with the fuel system, as shown in [Fig 40](#).

Fig. 40. Avro Lincoln Mk II tankers RE.293 and SX.993



Although there was a delay in the completion of converting the two Lincolns RE.293 and SX.993, the training programme and pattern of the evaluation trials were discussed between Flight Refuelling Ltd and Fighter Command. During these the company recommended that to facilitate interception with the tanker a radar responder beacon should be fitted to the Meteor receiver aircraft. The training programme commenced on 18 March, when seven squadron pilots and two ground engineers started a course of instruction at Tarrant Rushton, after which, on 29 March, initial receiver flight trials commenced using the Lincoln tanker RA.657. Squadron Leader C.F. Counter commanded the evaluation trials, and on his first contact received a large fuel splash, much to the concern of Flight Refuelling Ltd. However, on replacing the refuelling hose, all the pilots made successful contacts and fuel transfers without any difficulty. So successful was this part of the initial programme that 150 contacts were made in one day.

Phase 1 of the evaluation trials was to investigate the methods of receiver and tanker rendezvous, the practical method of refuelling formations of two to twelve receivers, the suitable refuelling speed, approaches to the tanker, height and weather conditions for satisfactory contacts; also pilot fatigue in long-duration flying, and the serviceability of the tanker's equipment.

Phase 2 would include problems of refuelling fighter aircraft in unfavourable weather conditions, extended aircraft range, night refuelling, and any problems that might occur during convoy and low-level patrols.

Flight Refuelling Ltd was to operate the three Lincoln tankers (RA.657, RE.293 and SX.993). Initially RA.657 was ready to participate, the second Lincoln was to be available by 1 June, and the third by 1 July, the latter aircraft acting as a spare. The aircraft would all be based at Tarrant Rushton, and RAF Coltishall was to be used during the evaluation as an advanced base. Prior to a day's operation, RAF Horsham

St Faith would inform Flight Refuelling Ltd of the time and height for the tanker to be overhead Norwich, the anticipated duration of the sorties and the required fuel for transfer.

The trials officially commenced on 8 May 1951, and they were to continue until all of the parameters of the task had been completed. However, it was not possible to relieve the squadron of normal operational commitments. At the time of commencement nine Meteors had been converted to the receiver role.

The Lincoln (RA.657) took off from Tarrant Rushton for the first sortie at 08.30 to rendezvous overhead Norwich at 12,000 feet altitude, ready for the interception of the first three Meteors. These made the rendezvous at 09.40, whereupon the first section approached the Lincoln. The leader made three contacts, accepting fuel successfully on the second one. However, the second and third pilots, being new to the technique, had some difficulty before making successful contacts. One aircraft on breaking away suffered a severe fuel splash, after which it was thought to be caused by failing to close the probe nozzle's fuel valve prior to making a disconnect. The second section of Meteors also made successful contacts, though after this, because of a damaged drogue on the tanker, the operation was aborted. The damage was due to receivers making a too fast contact, thereby overshooting and striking the drogue. The tanker returned to Tarrant Rushton and had to dump fuel to get the aircraft's weight down to its landing weight.

On 17 May, three Meteors returning from a flight over London were successfully refuelled, Squadron Leader Counter and the two other pilots being very satisfied with this achievement—the first experience in the practical application of flight refuelling—particularly as all three aircraft were low on fuel. During the trials contacts had been deliberately made in turbulent conditions with some success, although a few dents in the drogue and on the aircraft had

occurred. The average refuelling sortie for the Meteors lasted two hours, and for the tanker four hours. During these the average time for refuelling four aircraft, with each accepting 270 imperial gallons (1,215 litres) of fuel was in the order of sixteen minutes.

By 20 May, the training programme at Tarrant Rushton had been completed, and twenty-six pilots had been trained in the technique, including four from the Central Fighter Establishment. From early June, the squadron combined flight refuelling with other exercises, including a birthday flypast for King George VI, during which the Meteors refuelled in the air either before or after the event, and on several occasions they would not have been able to return to their base without refuelling.

For the first month of the evaluation trials, Lincoln RA.657 had been the only tanker used, as the second Lincoln had not completed its conversion, and the company's Lancaster G-33-2 was used from 8 June to cover the periods of RA.657 maintenance.

On 21 July 1951, a round-Britain flight was made by Squadron Leader C.F. Counter, with three air refuellings planned using Lincoln RA.657. These were to be carried out at an altitude of 15,000 feet, though the rest of the Meteor's flight was to be at 40,000 feet. After the second refuelling it became impossible to close the probe nozzle's fuel valve, thereby causing the third refuelling to be aborted.

However, the third refuelling had been planned to take place overhead Horsham St Faith, enabling the aircraft to land with full tanks. Even so the flight was a further success. It was later thought that the failure had been caused by the valve being iced up owing to the long low-temperature soak at altitude.

Following a further exercise on 1 August, no further refuelling sorties were planned until 3 October, which would then allow the second Lincoln, SX.993, to complete its

conversion and participate in future operations. It actually had its first handling flight on 23 August 1951.

The two Lincolns RA.657 and SX.993 took part in further trials on 3 October, both being put on standby at Horsham St Faith in readiness. Both were airborne at various times, but due to some confusion by the Horsham control, an instance occurred when one of the tankers had not been fully ground refuelled nor airborne at the time required, and this resulted in some Meteors having to land and refuel.

Night refuelling started on 9 October, whereupon the Meteor pilots found that there was no difficulty in making a contact, but problems did occur when attempting to intercept the tanker on the second time round. Nevertheless, the night operations were very successful once an interception had been made. The Meteor during these particular trials had been fitted with a 'lash-up' probe light, which greatly assisted the pilots.

To end the evaluation trials in what could be termed a 'Grand Finale', it was planned to fly three Meteors to Malta non-stop and return. In preparation for this flight three of them carried out a second round-Britain flight on 11 October, using wing drop-tanks and in-flight refuelling.

The planned Grand Finale was to take place on 30 October using three tankers, RA.657, SX.993 and either Lincoln RE.293 or the company's Lancaster G-33-2. However, at the time of planning, RE.293 had not completed its conversion, although it had carried out its first flight on 29 October and was to be used. One tanker was to be based at RAF Tangmere, and the other two at Istres, France. The Tangmere-based tanker was to refuel the four Meteors near to Paris, then return to Tangmere to be used as a back-up on the return flight. The tankers at Istres were to refuel the aircraft overhead Istres, one tanker being used for this part of the flight, although both were to be airborne in case of any problems occurring with one of them. The return flight

was to take place on 1 November, the tankers being used in the reverse operation.

Owing to the tense international situation prior to the date of the final flight, the AOC of 12 Group decided that the proposed flight to Malta only be given the go-ahead nearer the date of the operation, even though the planning and preparation had been completed. On 22 October the flight was cancelled as the political situation had not improved. It was hoped that it could now be carried out in the spring of 1952, when it thought that an improvement in the situation would occur. Fighter Command then suggested that if the flight was made it intended to use the Avro Tudor aircraft as a tanker, because the Lincolns would have been reverted to standard. Also, these aircraft were available, as a number were in storage at Tarrant Rushton.

During the evaluation trials the squadron Meteors flew a total of 374 hours, making 672 contacts and transferring 58,685 imperial gallons (264,082 litres) of fuel during 219 refuelling sorties. However, before the trials had been completed a conference was held to consider the future of Command policy on in-flight refuelling.

After the trials the Meteor aircraft that were involved were eventually disposed of in the 1950s. The following table shows when they were either struck-off-charge or delivered to another air force.

WA.830	24/APS Syla	Struck-off-charge	21-10-59
WA.823	245 Sqdn	Sold as scrap	12-8-59
WA.826	24/APS Syla	Sold as scrap	14-9-59
WA.827	245 Sqdn	Dived into ground nr Horsham St Faith	19-5-51
WA.828	257 Sqdn	Sold as scrap	29-6-59
WA.829	245/APS Syla	Struck-off-charge	15-4-59
WA.832	245/RAFFC	Sold as scrap	12-5-58
WA.834	245/APS Syla	Sold as scrap	24-4-59
WA.836	245/74	Broke up during Aerobatics, Conningsby	19-9-53
WA.837	245/APS Syla	Struck-off-charge	6-10-59
WA.936	To RAAF	As A77-373	8-1-51
WA.938	To RAAF	As A77-29	8-1-51
WA.941	To RAAF	As A77-163	3-1-51
WA.946	To RAAF	As A77-911	8-1-51
WA.952	To RAAF	As A 77-368	8-1-51

Squadron Leader Counter had reported the progress of the trials, and stated that there had not been any pilot fatigue, and that refuelling could be carried out in any weather providing the receiver aircraft could maintain visual contact with the tanker.

Asked about his opinion of a suitable future tanker, he expressed a preference for a three-point tanker after the experience the squadron had gained from the demonstration of simultaneous refuelling with the Boeing YBT-29T Superfortress three-point tanker. Also, in view of the fuel capacity of future fighter aircraft, a tanker would require 5,000 imperial gallons (22,500 litres) of transferable fuel, and should be capable of operating at 200 knots at an altitude of 25,000 feet.

The C-in-C of Fighter Command stated that it was obvious that the cost of refuelling in flight would be high, and that providing tankers would reduce the number of fighter aircraft. Although the value of flight refuelling was indisputable, the benefits to the Command would be unlikely to compensate for the cost of development and reduction in fighter strength. He was therefore against the introduction of the technique in his Command for the present, though future fighter aircraft should incorporate the provision for the technique.

Therefore, with no early adoption of air refuelling, and with the possible use of the Avro Tudor as a tanker for the now doubtful Malta flight, it was agreed that there was no further use for the three Lincoln tanker aircraft.

Instructions were given to Flight Refuelling Ltd to revert the three aircraft to standard, and return them to service. RA.657 had been used for over a year, including doing development work, SX.993 had been only briefly used and RE.293 had just completed its acceptance flight. All three aircraft were disposed of in 1952. The first to go was RE.293 on 1 May, followed by SX.993, and finally, on 14 July,

RA.657. Although the Meteors retained their refuelling probes, they were not used operationally except for WE.934, which was involved in a brief trial with the Canberra tanker WH.734.

After all the development, demonstrations and evaluation, Fighter Command had put off adopting the air-refuelling technique indefinitely, although the Air Ministry was studying other operational uses. For some years Sir Alan Cobham had been advocating refuelling in flight for the new bomber aircraft (V-bombers) that were in the process of design and development, saying that a tanker version was the way ahead. In June 1952 he put forward a report recommending that the Handley Page 80 bomber (eventually known as the Victor) be converted into a tanker. He showed that by having a proportion of bombers as tankers they could be used to refuel the fighter escort during long-range sorties. One HP.80 would be capable of refuelling ten fighters over an effective range of 1,300 miles. Later in 1952 the Air Staff agreed in principle to use flight refuelling, possibly with the Vickers Valiant as a tanker.

In 1951, further development of the Mk IX hose-drum unit, originally designed for the Boeing B-29 three-point tanker, commenced, and was for experimental purposes to improve its performance. The improved hose-drum unit was designated the Mk XIV, for use within the fuselage of a large bomber aircraft. The main feature of its development was to ensure that it could transfer fuel at a higher rate of flow—at 300 imperial gallons (1,350 litres) per minute—which would reduce the time of large aircraft remaining in contact, as well as facilitating the location of the unit within the fuselage at virtually any position. The unit is shown in [Fig 41](#).

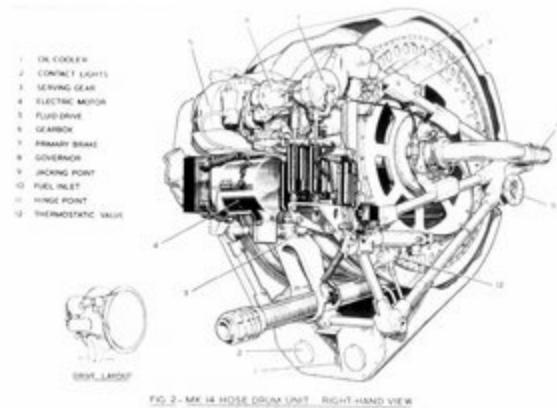


Fig. 41. Mk XIV hose-drum unit

To achieve this improvement it was necessary to increase not only the bore of the refuelling hose but also its length, and it required a larger hose drum to fit within a slightly modified structure of the Mk IX.

Two Mk XIV hose-drum units were built, the first being installed in Lancaster G-33-1 for development flight trials.



Mk XIV hose-drum unit in Lancaster G-33-1

Eventually both units were sold to the USA for further flight trials with the American Air Force, at which time the the probe and drogue system was in competition with the

Boeing boom method of aerial refuelling. One unit was installed in the Boeing B-47B Stratojet bomber with the hose drum unit in the aircraft's bomb-bay.



The other was installed in a Convair B-36, which had a retractable boom through which the refuelling hose was trailed.

The retractable boom provided a good vertical separation between the tanker and receiver.



Convair B-36 bomber

The trials were successfully carried out, but the Boeing

boom was accepted for operational use with the United States Air Force.

In September 1951 the Air Staff were again interested in the refuelling of the English Electric Canberra bomber. It was agreed that a flight trial should be carried out with Flight Refuelling Ltd's Lancaster tanker aircraft G-33-2. The trial was to assess the formatting positions for the Canberra in order to discover the best position for locating a receiver probe. After a short familiarization flight in the Canberra, Pat Hornidge flew the aircraft in several formatting positions successfully, and at the same time gave consideration as to which would be the best position for the probe. It was concluded from the pilot's point of view that a nose-mounted probe was the solution, and this was finally recommended. At the same time, the Air Staff were now giving serious thought to air refuelling the Canberra, and had concluded that it would provide a greater radius of operation. However, others were contemplating its use in the forthcoming England-New Zealand air race. Nevertheless, neither of these proposals was taken up, although several Canberra aircraft took part in the race. In early 1953, the Air Staff, having abandoned the Canberra proposal, decided that they were going to adopt the probe and drogue technique for the whole of the V-bomber Force, namely the Handley Page Victor, the Vickers Armstrong Valiant and the Avro Vulcan. This decision had come about after Flight Refuelling Ltd had presented lectures, articles and demonstrations, together with the American Air Force's experience, which proved that it was economically viable, and that large advantages were to be gained by the increases in range of all the aircraft.



Convair B-36 retractable boom

The requirement laid down by the Air Staff for the introduction of the technique was that the operation should be capable of being carried out at altitudes up to 40,000 feet, at an airspeed of 300 knots and with a fuel flow transfer rate of 500 imperial gallons (2,250 litres, or 4,000 lb) per minute.

A further development of the hose-drum unit was commenced in 1952, incorporating the use of a liquid spring for braking purposes. The new method abolished the necessity of having two separate braking systems. The introduction of this enabled the hose-drum unit brake to be automatically applied via a mechanical drive at the full trail position of the refuelling hose; or automatically/manually in the event of an emergency. The new design was designated as the Mk XV hose-drum unit, and was a development of both the earlier Mk IX and Mk XIV hose-drum units.

The Mk XV hose-drum unit, although it was of an improved design, and was really aimed at the American Air Force, was a basic piece of equipment for the passing of fuel between two aircraft; it did not have a fuel-pumping or control system incorporated, simply because at the time that was considered to be the responsibility of the parent aircraft company. However, Flight Refuelling Ltd did have a lot of experience in the pumping of fuel, together with controlling it, and was in the process of considering a further

development of the Mk XV unit, which would incorporate a fuel-pumping facility and its control in what was to be termed a 'Refuelling Package'.

The V-bomber concept included that the refuelling package should be such a piece of equipment as could be easily removable from the tanker aircraft.

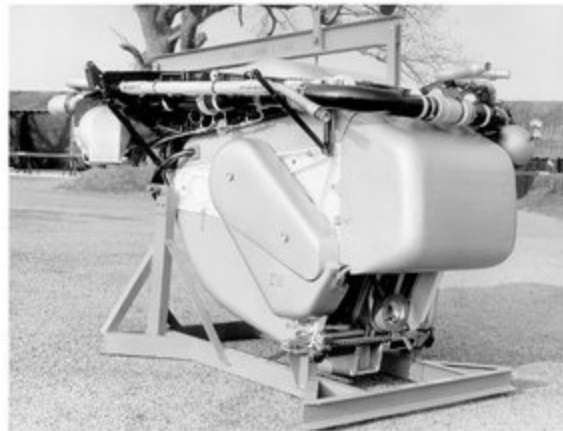
The Air Staff had determined that the Vickers Armstrong Valiant would be the tanker with one refuelling point, and that it should be capable of refuelling all three types of bomber aircraft, and the Ministry of Supply informed Flight Refuelling Ltd and Vickers Armstrong Ltd that the initial requirement was for three Valiant aircraft to be equipped with the new Mk XVI hose-drum unit refuelling package for development and evaluation purposes.

The first meeting to discuss the Valiant conversion into a tanker was in early April 1953 at Weybridge, Surrey. The initial conclusion made was that the refuelling package should be of a retractable type located at the rear of the aircraft's bomb-bay, and should incorporate the new automatically operated Mk 6 reception coupling, and all receiver aircraft should have the matching Mk 6 probe nozzle fitted. Thus, with this new piece of equipment, it would no longer be necessary for the receiver pilot to open the probe nozzle's fuel valve on making a contact.

During the considerations given to equipping the V-bomber Force, thoughts were also given to the new proposed Handley Page 99 low-level bomber. This aircraft was to carry a rocket-propelled nuclear missile, taking off with a minimum fuel load (Sir Alan Cobham's original concept), then having 90,000 lb (11,250 imperial gallons, or 50,625 litres) of fuel transferred to it. During the early discussions it was concluded that the aircraft would require equipment capable of passing fuel at a rate of 1,000 imperial gallons (4,400 litres) per minute, at an airspeed in excess of 300 knots.



Mk 16 refuelling package



To cater for this requirement a new design of hose-drum refuelling package would be necessary with a larger bore of refuelling hose, and an uprated fuel pumping and control system. However, with Flight Refuelling Ltd's experience it was not considered to be beyond the company's capability, and it conceived the Mk XIX refuelling package. Nevertheless, once again the low-level bomber project was cancelled, but the development of the new unit continued for possible future applications, as the reader will learn later.

By early 1954, the Air Staff confirmed the requirement for the V-bomber Force, deciding that all Victors and Vulcans were to be modified to be capable of receiving fuel in flight, and that the Valiant tanker should be given this capability.

The requirement for tanker aircraft was later changed to all the V-bombers being given the capability of becoming tanker aircraft, and that all the necessary fixed fittings required for the conversions should be introduced on the earliest production aircraft as soon as possible, together with retrospective modification to earlier aircraft.

Once again the requirement was later changed, in that the Valiant alone should be the tanker. Originally the total order for tanker aircraft conversions was to be for eighty-one aircraft; however, the order came too late for the first fifty aircraft on the production line.

During the early technical discussions it was eventually decided to install the Mk XVI refuelling package as a fixed installation located at the rear end of the Valiant's bomb-bay. To enable the aircraft's air, electrical and fuel system to interconnect with the package, a mock-up of the whole refuelling package was built, as shown below. This was then installed in the prototype aircraft, as shown.

To support the tanker project and provide early technical information from the higher speed and altitude range requirement, in July 1953 Canberra B Mk 2 WH.734 was delivered to Tarrant Rushton. This aircraft had the Mk XV. Hose-drum unit installed at the forward end of its bomb-bay, together with a small fuel pipe connected to the No. 3 fuel tank. The latter provided a small quantity of fuel to enter the refuelling hose, thus allowing the hose to fly at the correct trailing angle throughout the altitudes and the speed range. The Canberra is shown above with Valiant WZ.390 in contact.



Canberra WH.734 to Vickers Valiant

However, the first official refuelling trials for approval with the Valiant aircraft took place at A&AEE Boscombe Down in November 1955, using the specially modified aircraft WZ.376 as the tanker, and WZ.390 as the receiver.



Valiant to Valiant

Earlier contractor's trials using these two aircraft and Canberra WH.734 found problems with the then standard drogue at the much higher airspeeds that were now required. When a receiver attempted to make a contact, the receiver aircraft's bow wave displaced the drogue away from the nose-mounted probe, thereby causing the pilot to miss the contact. To overcome this problem various-shaped drogues, together with an inflatable type, were used, but without much success. During these trials, an investigation was being carried out into the behaviour of the airflow around the drogue by Flight Refuelling Ltd at Tarrant

Rushton. The investigation made use of an air bubble tunnel (Fig 42) in which scale-model drogues were mounted, and pressurized air was fed into it via a streamlined strut, and mixed with fuel being pumped through it, causing lines of bubbles to pass over the model.

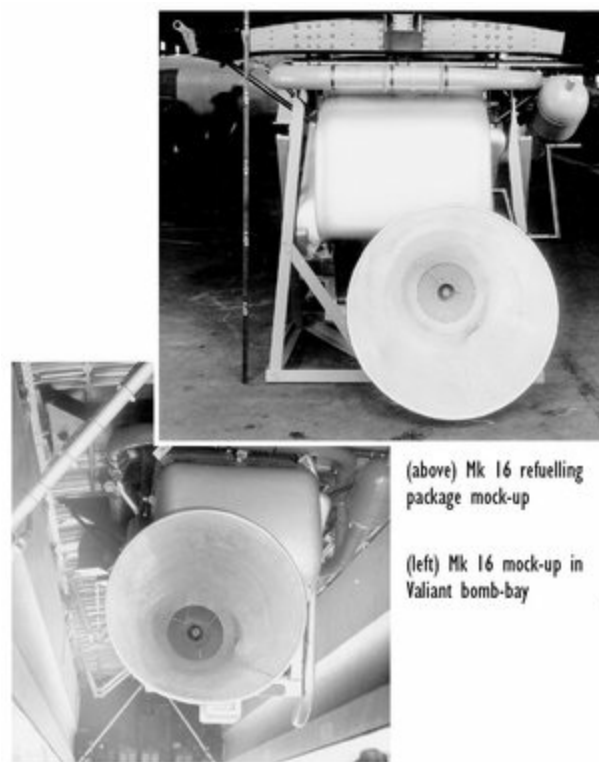
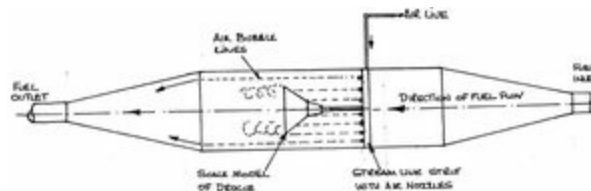


Fig. 42. Diagram of air bubble tunnel



The result of this investigation indicated that to overcome the problem the drogue should be ventilated to allow the bow wave to pass through the conical shape. All drogues at this time were manufactured from sheet metal rolled into a

cone, thereby making it what was termed a 'Solid Drogue'. The new package's drogue was then modified by the introduction of spokes and a drag ring at its periphery, the former permitting the bow wave to pass through it, and the latter to maintain the required drag load. Further air testing showed a much improved performance, the bow wave problem having now been overcome.



Ventilated drogue

During the initial contractor's trials several problems arose. Initially a refuelling hose length of 105 feet was employed, but this was found to oscillate vertically at certain airspeeds, making a contact virtually impossible. It was overcome by reducing the overall length of hose trailed to 80 feet, which also improved the refuelling position, as any movement by both aircraft coincided with each other, thus avoiding separate bumping.

Also, during fuel transfers the main fuel-transfer pump within the refuelling package would hunt, therefore not providing a smooth control over the fuel flow. Nevertheless this was overcome by the insertion of a damping bottle in the pump's power supply line (see Valiant tanker system).

The Valiant having completed the contractor's trials and A&AEE Boscombe Down's approval testing, in which all the

V-bombers made refuelling contacts, is typically shown in Fig..., Valiant to Vulcan.

The testing included ground fuel-flow testing, wet and dry contacts in the air, and confirmation of the speed envelope through the altitude range, after which the Royal Air Force commenced operational trials in March 1958.

These were initiated by No. 214 Squadron based at RAF Marham, Norfolk, under the command of Wing Commander M.J. Beetham (later to become Marshal of the Royal Air Force Sir Michael Beetham GCB, CBE, DFC, AFC). The squadron was tasked with two trials known as No. 306 and 306A. The former was to test the compatibility of the receiver and tanker equipment, the latter to develop up-to-date rendezvous procedures. As these programmes of trials were now of great urgency, the initial training of both air crew and ground crew was carried out by Flight Refuelling Ltd at Tarrant Rushton, and a Flight Refuelling School was developed at RAF Marham. In the early stages of these trials, dry contacts only were made, as it was found that there was an incompatibility of the aircraft's electrical and radar equipment with the receiver. These problems were overcome by either repositioning or switching equipment. By January 1959 two modified tankers in the receiver role began wet transfers, the tanker being capable of transferring 45,000 lb of fuel (5,625 imperial gallons, 25,312 litres), at a rate of 500 imperial gallons (4,000 lb, 2,250 litres) per minute.



Valiant to Vulcan

During this activity various official record flights were achieved, and are worth mentioning below.

With the introduction of flight refuelling as a task within the RAF, both air and ground crews enjoyed the new challenges, the main one being the exacting task of the air crews to fly as receivers. The ground crews were more fortunate with the longer-distance flights, which were becoming an Air Force commitment; when they were able to enjoy the new opportunities of visiting Karachi, Nairobi, and Gan. By May 1960 the trials were successfully completed, and one of 214 Squadron's Valiants set up a new record for a non-stop flight. The aircraft flew 8,110 miles from RAF Marham to Singapore, Malaya, in 15 hours 35 minutes, at an average airspeed of 523 mph.

1. RAF Marham, Norfolk, to Aden
2. RAF Marham, Norfolk, to Nairobi
3. United Kingdom to Johannesburg
4. United Kingdom to Capetown
5. Longest jet flight (at the time) by RAF aircraft

7 hours 10 minutes
7 hours 40 minutes
11 hours 3 minutes
11 hours 28 minutes
18 hours 28 minutes,
covering 7,400 nautical miles

Nevertheless during the training programme accidents did occur, in that when making a contact the receiver attempted a contact at too high a speed. This caused a hose whip, as the contact speed was greater than the hose unit's response, and this caused lost nozzles and bent probe tubes, as shown

on the Victor below.



Victor with bent probe

Fighter aircraft such as the Gloster Javelin and English Electric Lightning were now being fitted with refuelling probes to enable them to remain airborne for longer periods.



Valiant to Lightning refuelling

Receiver training of the Javelin commenced in June 1960 with No. 23 Squadron. After they had been refuelled out to Akrotiri, Cyprus, and back in August 1960, four Javelin aircraft were refuelled from the United Kingdom to Butterworth, Malaya, in five days during October. Their route was via Akrotiri, Bahrain, Maripaur and Gan. In December

No. 64 Squadron started its Avro Vulcan training in air refuelling, and at that time the air crews of No. 617 were training for a non-stop flight to Australia with their Vulcan aircraft. The Vulcan progressed with non-stop flights from RAF Scampton to Nairobi (being refuelled over Idris), to Karachi and back, culminating in June 1961 with the first non-stop flight from the United Kingdom to Sydney, Australia, in 20 hours 3 minutes, having been refuelled overhead Cyprus, Karachi, and Singapore. This was followed in July 1963 by three Vulcans of 101 Squadron flying non-stop to Perth, Australia, from RAF Waddington, Lincolnshire, a distance of 9,900 miles, in 18 hours 16 minutes.

Appropriately on 1 April 1962 (forty-four years to the day after the formation of the Royal Air Force), Nos 214 and 90 Squadrons officially became the first tanker squadrons, losing their bomber commitment. Operational training continued with the Vulcans of No. 50 Squadron, the Victors of No. 57 Squadron and the Lightnings of No. 56 Squadron, and later with the de Havilland Sea Vixens of No. 899 Squadron, Royal Navy.

Now that refuelling in flight had become a commitment, and all military aircraft were being fitted with refuelling probes, some mention of their fuel system, together with the positioning of the actual probe, is required.

All modern-day aircraft are fitted with a ground-pressure refuelling system, which operates in a similar manner to that of flight refuelling. It is therefore only necessary to tap a fuel line into this system to convert an aircraft into a receiver.

The Valiant's refuelling probe was fitted to the front of the NBS radar scanner bay at the nose of the aircraft. The English Electric Lightning, however, originally had a retractable probe sited to be

installed on the port side of the Lightning mock-up fuselage adjacent to the cockpit. This assembly was mocked-up as shown, and an assessment was made not only of its

design features but also of the pilot's view of the probe nozzle, as illustrated. This proposal was not accepted, as can be seen, and it was eventually mounted under the port wing, and was used for ferrying purposes.

Meanwhile the Valiant became a highly successful tanker, and in 1961 a joint exercise with the Americans took place. Before this could take place, however, it was necessary to introduce a new probe nozzle on the receiver aircraft and a reception coupling on the tanker. The Americans were using the MA.2 probe nozzle and reception coupling at the time, which was not compatible with the British equipment. To achieve the compatibility between the two forces there was a competition on whether the Mk 6 British equipment or the American MA.2 should be used. It was finally decided to introduce the MA.2 equipment onto British aircraft. Nevertheless it did not retain the American designation, but became the Mk 8 probe nozzle and reception coupling.



Although the original intention of the Valiant tanker was to

extend the range of the V-bomber Force, in practice the technique was mainly used to enable rapid deployments to be made, and the shortcomings of the Valiant's single refuelling point was demonstrated. Additional tankers were required as airborne spares in case of equipment failure, and this factor, together with the frequent number of refuellings required by the Javelin and early Lightnings, necessitated a large tanker force for a small number of fighter aircraft.

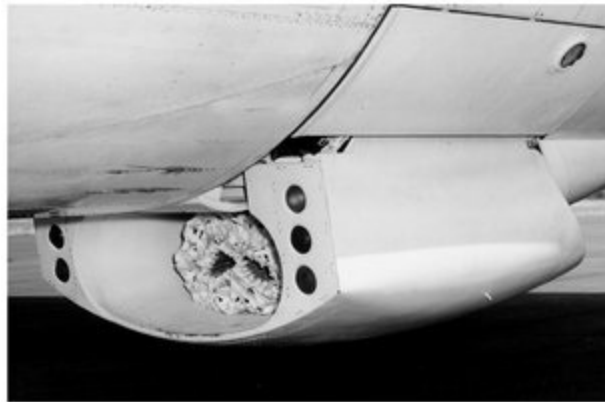
A two-point Valiant tanker was considered, using under-wing 'Buddy-Buddy' refuelling pods that were being developed for the Royal Navy (the development of this system is described in a later paragraph); however, the two-point Valiant was not produced.

Nevertheless, other services made use of the Valiant tanker, including the Royal Navy, which introduced air refuelling in the 1960s with the Vickers Supermarine Scimitar and the de Havilland Sea Vixen. The previously mentioned joint RAF/USAF exercise held in 1961 demonstrated the compatibility between the two air forces when the Valiant refuelled American B-66, F.106 and F.101A receivers, and the B-50 (a later version of the B-29 Superfortress) tanker refuelled the Valiant, Vulcan, and Victor receiver aircraft.

The Royal Air Force having gained a vast experience in the operational techniques of air refuelling, together with successful operation of the Mk XVI refuelling package, the Air Staff issued in May 1962 an Air Staff Preparation Document No. 50, for the conversion of the Handley Page Victor B Mk 1 bomber into a three-point tanker, as the Mk 1 was to be replaced by the Victor B2.

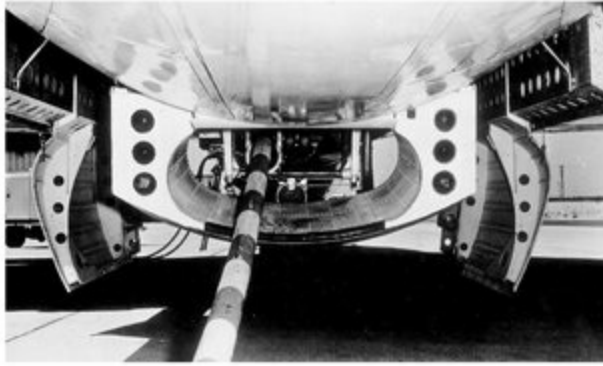
Both Handley Page and Flight Refuelling Ltd responded to the Preparation Document, the former completing a design study of the conversion by September 1962, and the latter a design study of the equipment recommended to be used, and this was completed in October 1962.

The first meeting to discuss the design involved in the conversion was held with Handley Page Ltd at Cricklewood, London, when Peter MacGregor and I met Mr G. Ward to determine the installation of the refuelling equipment. The newly proposed Mk XVII package was an improved version of the original Mk XVI Valiant equipment, and was to be a similar installation—a fixed installation located at the rear end of the aircraft's bomb-bay. However, several schemes were tabled, one of which was a retractable design, which showed the package attached to a retractable platform secured to the bomb-bay roof, and attached to it a large scoop fairing to accept the reception coupling and drogue.



Victor retractable fairing, Mk 17 hose-drum unit

The photo below shows the width of the scoop, which provided ample travel for the hose-drum serving carriage and receiver aircraft movement, together with good receiver visibility of the three contact lights.



Victor fairing, showing contact lights

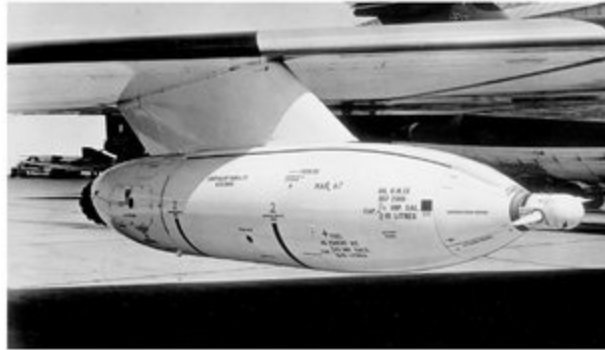
The complete assembly was to be located at the aft end of the aircraft's bomb-bay, and when retracted provided a smooth underside to the fuselage, removing the necessity to open the bomb-bay doors prior to a refuelling operation. This option was chosen as the best installation and was accepted by the then Ministry of Aviation.

The two wing refuelling units to complete the three-point configuration were to be the Mk 20A Naval Refuelling Pod, so aiming for standardization of refuelling equipment. However, although it was proposed to install the pod on an under-wing pylon, the soleplate of which would conform to the existing standard of Arm.E.8467, this could not happen due to the position of the Victor's pylon fuel line. Therefore a new fuel inlet to the pod had to be made, positioned forward of the existing suspension point of 3 inches (76.2 mm) diameter, so that the pod now had two fuel inlets, making it compatible with the naval aircraft and the Victor. It now became a variant of the Mk 20A, and was designated the Mk 20B. The transfer fuel flow rate was, as per the naval version, 150 imperial gallons (675 litres) per minute. The new tanker could therefore refuel two fighter aircraft at once, and if there was a pod failure one aircraft could refuel from the fuselage unit, thus saving a sortie from being abandoned.

The new tanker still had the capability of refuelling the

larger transport aircraft like the VC.10, etc.

The Mk 20B is shown below mounted on the Victor's starboard wing.



Victor, with Mk 20B refuelling pod

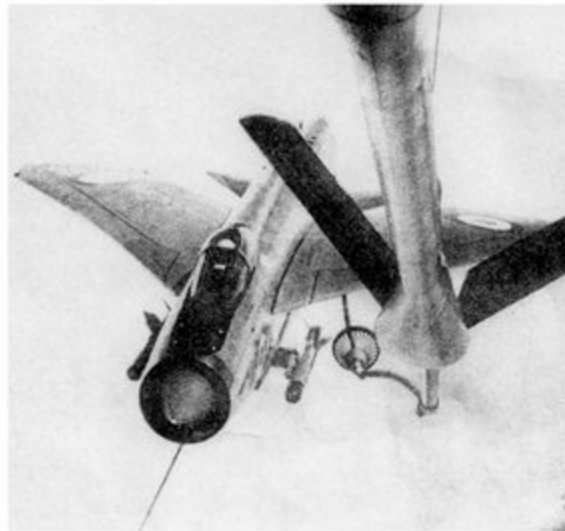
To control the refuelling operation the operator was provided with three panels, one of which was similar to the Mk XVI, and two standard Mk XXA panels, these all being located at the Nav radar operator's position in the cockpit, as shown above.

However, the Valiant continued to operate as a tanker, and underwent many more overseas trials and exercises successfully until January 1965, when No. 214 Squadron was disbanded following the discovery of metal fatigue in the Valiant's wing spar. The government at the time concluded that to attempt a rectification was unjustified, as it was intended to replace the Valiant with the Victor tanker from 1967. The sudden demise of the Valiant created a serious gap in the air-refuelling capability of the Royal Air Force, and a further series of trials were carried out using the Victor and Lightning receivers with the American KC.135. The boom tankers had their booms modified to accept a short piece of refuelling hose with a reception coupling and drogue attached at its base, as shown below.



Operator's panels, Victor tanker

These trials were successfully completed, and provided an interim capability, and during this period six Victor Mk 1As were withdrawn from squadron service to be put through a rapid conversion programme to a two-point tanker configuration. Treasury approval for the three-point Victor was given in November 1963, and there was now some urgency for the two-point configuration.



American boom refuelling Lightning

The first was XH.620, which was flying on 28 April 1965, followed by XH.667, XH.648, XH.647, XH.615 and finally XH.646. Four more Mk 1As of these aircraft were delivered to No. 55 Squadron during May and June 1965, these being fitted only with the two Mk 20B refuelling pods and control panels.

The urgent requirement for a tanker service led to the interim aircraft being released to the squadron after a minimum time at A&AEE Boscombe Down. Early flying therefore included trials to obtain fuel consumption and performance data at the speed and altitude ranges for the aircraft in its new configuration. With respect to the compatibility to transfer fuel to Lightning receivers, all phases of the trials were successfully carried out and the Lightning pilots practised refuelling in pairs behind the wing pods.

To clear the two-point tanker for overseas operations and route-proving flights this took place in August 1965. Later that month-less than three months after the formation as a tanker squadron-No. 55 Squadron flight-refuelled Lightnings of No. 74 Squadron, Leuchars, from Wattisham to Akrotiri, and returned with No. 19 Squadron to Leconfield. This needed five out of the six tanker aircraft to be serviceable throughout the operation. The sixth and last two-point arrived at Marham in September 1965. A typical air refuelling of the Lightning from a wing pod is shown below.

Victor refuelling Lightning from wing pod



In addition to displays including static and flying with receivers in contact, No. 55 Squadron, with the two-point tanker, carried out the following air refuelling operations:

1. Four Lightnings of No. 74 Squadron to Tehran for the Iranian Air Force Day on 17 October 1965
2. Flight trials with a Boscombe Down Buccaneer
3. Lightnings to Jordan in December 1965 on demonstration tour
4. Ground and air compatibility trials with the USAF F.100 aircraft in March 1966
5. First interception of Russian aircraft in UK airspace
6. Trials with Mk 6 Lightning, flight refuelling training of BAC pilots and subsequently ferrying BAC Lightning M.52 and M.53 to Saudia Arabia.

One of the trickiest sorties was during the making of the film *Cavalcade of the Air* for the BBC to celebrate the 25th Anniversary of the Battle of Britain, in which two Lightnings struggled to remain in contact with the tanker at low altitude at 220 knots.

During the eighteen months that the two-point tanker was in service, 6,718,700 lb, or 83,984 imperial gallons, of fuel was transferred in 3,143 'wet' contacts out of a total of

10,646 contacts, and thirty-nine overseas exercises had been carried out.

Meanwhile, at Radlett work was proceeding on the conversion of ten Victor B1s as full three-point tankers. None of these aircraft kept its bombing capability. The first aircraft, XA.937, flew on 2 November 1965 with the designation Victor K1. This aircraft subsequently went to A&AEE Boscombe Down for trials, then like the others went to No. 57 Squadron, which moved to Marham in December 1965 to convert to the tanker role. At a later date three-point conversions were made from Victor B1As.

However, it was during a visit to Flight Refuelling Incorporated in the USA in 1954 that Sir Alan was shown the progress that was being made with the 'Buddy-Buddy' concept of air refuelling. This was being developed for the American Navy, and possibly the American Air Force. The 'Buddy-Buddy' concept was designed for fighter and bomber aircraft; where the hose-drum unit reception coupling and drogue, together with a power source, were incorporated in an under-wing drop tank. The design permitted this type of drop tank to be fitted to various aircraft types as a standard fit, the parent aircraft being capable of dispensing fuel to a receiver aircraft, or using it for its own purpose, and it could be replenished during a refuelling operation.

Sir Alan thought that Flight Refuelling Ltd in England was capable of designing such a system for the Royal Air Force. It was the Royal Navy, however, that first operated the concept, which became a self-contained ram air-turbine-powered pod that was easily attached to or detached from a standard under-wing pylon of fighter and strike aircraft. The pod could be operated at altitudes up to 45,000 feet, at operational airspeeds of 310 knots EAS, carried in the non-operating condition up to 500 knots or Mach 1.0, and also having the capability of being carried during an aircraft-carrier catapult take-off and arrested landing. Dimensionally the pod was 13 feet 7 inches in length, 28 inches in

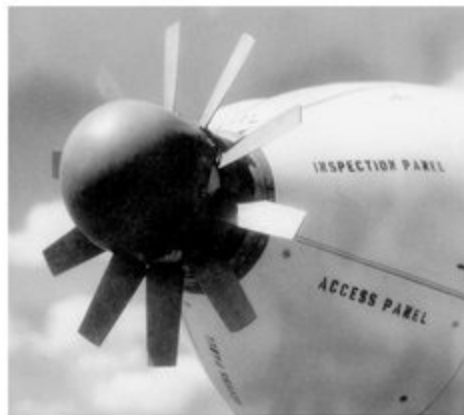
diameter, and apart for some small electrical requirements was self-contained in power, also having the capacity of 150 imperial gallons (675 litres) of disposable fuel, and a transfer flow rate of 150 gallons per minute.

Six variants of the refuelling pod were ultimately designed and manufactured, and a further two were proposals that at the time did not come to fruition.

The refuelling pod was designated as the Mk XX, this being the first prototype, and it was initially flown on Canberra WK.143, as shown below.



Canberra WK.143 flight-testing Mk 20A pod

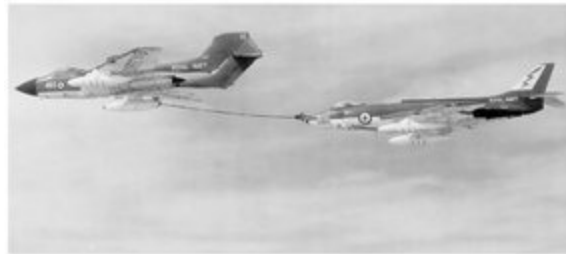


Prototype ten-bladed ram air turbine

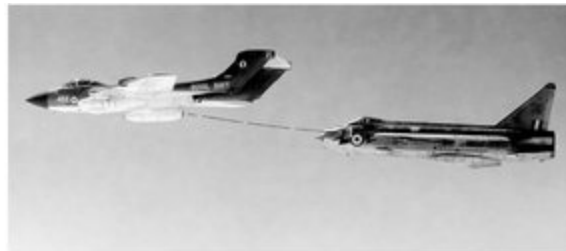
This pod initially used a Dowty Rotol ten-bladed constant-

speed ram air turbine to provide the necessary 36 horsepower to power the fuel pump and hose-drum unit, as shown below left.

A solid-type drogue similar to that on the Valiant, but smaller, was used on the first Vickers Armstrong Scimitar and de Havilland SeaVixen tankers of the Royal Navy, as shown below.



Sea Vixen refuelling Scimitar



Sea Vixen refuelling Lightning

For this version of the drogue it was necessary for the rear end of the pod to have what was termed a 'Bluff End', which was triangular in shape, as shown below.



Prototype Mk 20 bluff-ended refuelling pod

This equipment went into service in the early 1960s. However, after a short period the bluff-ended pod was modified to a streamlined shape that accepted a collapsible-type drogue and was designated as the Mk 20A, as shown below.



Mk 20A refuelling pod



Mk 20A refuelling pod drogue stowage

The Royal Navy also took part in the refuelling interchange with the American Air Force, having introduced the Mk 8 reception coupling and probe nozzle. To demonstrate the flexibility of the probe and drogue system; four aircraft linked up in line astern making a contact on the aircraft in front. Led by the Sea Vixen, a Sky Hawk engaged, followed by a Sky Warrior and finally by the Scimitar, as shown below.

During the 1950s and 1960s, not only were the Services busy training and converting their squadrons, but Flight Refuelling Ltd was involved in many design proposals and the development of equipment.

Firstly there was the Mk XIX refuelling package, which was proposed to refuel the Handley Page 99 bomber. This was to follow the original thoughts that Sir Alan Cobham had for getting an aircraft off light in weight, with an increase in the all-up weight to a maximum by refuelling in flight. The design of the package incorporated some of the ideas that were incorporated in the Mk XVI package. Nevertheless, to achieve the higher fuel flow rate required for the HP.99 previously mentioned of 1,000 imperial gallons per minute, the hose size had to be increased and the pumping of the fuel also needed further investigation. The fuel pumping was to be achieved by the use of two of the fuel pumps employed on the Mk XVI package. Likewise the refuelling hose bore was increased by one inch in diameter.

The design of this package was a large fairing structure to fit into the rear of the bomb-bay of the Victor/Vulcan aircraft complete with the hose-drum unit, fuel system and control, and retraction system for the hose-drum unit, together with the fairing doors. This is shown in mock-up below. As an interim measure it was also proposed to incorporate the Mk XVI hose-drum unit, thereby increasing the tanker aircraft

fleet prior to the HP.99 coming into service.

In the mid-1950s a requirement for a Blackburn Buccaneer tanker was given serious consideration, which was to be another refuelling package installed within its bomb-bay. This package was to be capable of transferring 300 imperial gallons (1,350 litres) per minute, with the fuel pressure at the reception coupling the standard 50 psi (3.4 bar). The equipment was designated as the Mk XXI, and the hose-drum unit and the fuel pump were to be hydraulically powered, mounted on a fuel tank structure. The whole package was built in a mock-up form to enable the electrical, hydraulic and fuel interconnections to be confirmed.

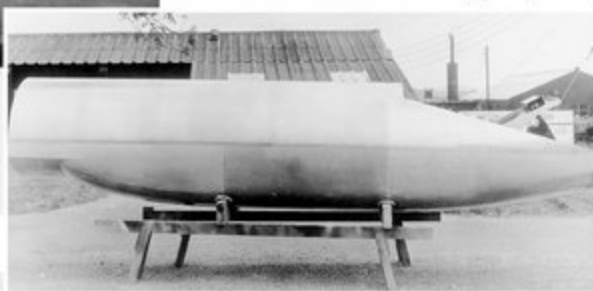


Mk 19 refuelling package mock-up

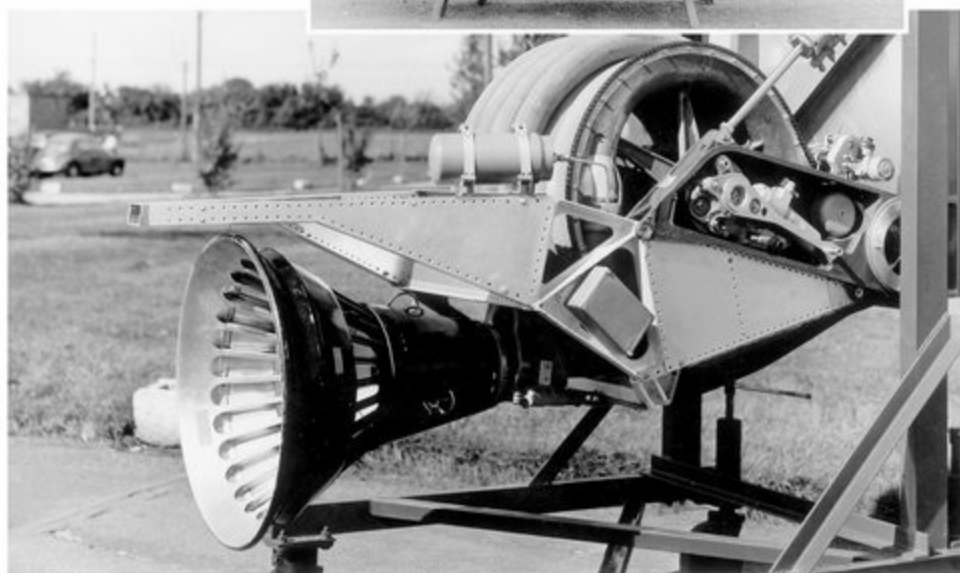
Four in contact, showing flexibility of system



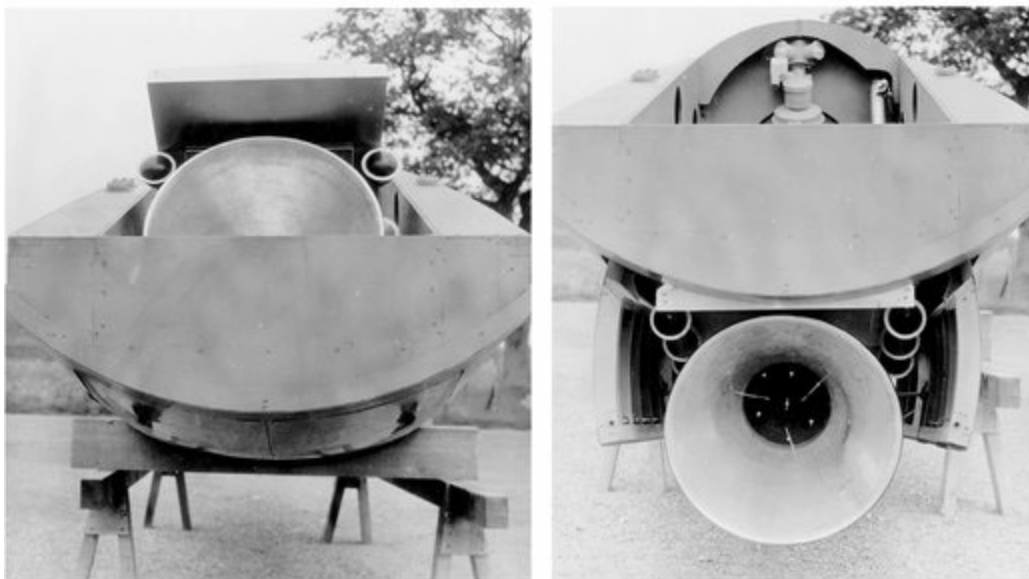
Mk 21 refuelling package mock-up in
Buccaneer mock-up



Mk 21 refuelling package mock-up



Mk 21 hose-drum unit



And to prove the ground handling for installation into the aircraft's bomb-bay, together with access for ground servicing, the mock-up was installed in the Buccaneer aircraft mock-up.

The hose-drum unit was located at the rear end of the package within its own bay and enclosed by retractable doors. The basic Mk XXI hose-drum unit is shown opposite, mounted on its ground handling stand.

The rear end of the Mk XXI refuelling package mock-up (opposite) shows the hose-drum unit in the lowered position, and also shows it with the unit retracted.

The basic Mk XXI hose-drum unit was completed and was undergoing initial testing when the contract for the project was cancelled.

However, the Buccaneer, through a more economic proposal, became a tanker, which was achieved by incorporating a variation of the Mk 20A refuelling pod. The pod became the Mk 20C through the necessity of minor installation modifications, and was installed under the starboard wing of the aircraft, as shown below refuelling an F-4 Phantom.



Buccaneer refuelling F-4 Phantom

Nevertheless, there was no let-up in refuelling projects during this period. Helicopter refuelling was being considered, firstly in respect of ship to helicopter. This was suggested as Alan Bristowe gave thought to refuelling helicopters of fishing fleets at sea from trawlers ahead of the factory ship. Eventually this did come into military use, with the navies of the world using frigates, etc. for the operation. Nevertheless, a trial took place to see if the looped hose method of refuelling could be adapted for helicopter-helicopter air refuelling. The trial was based on the cross-over contact method, where the tanker helicopter trailed a hose, and the receiver trailed a grapnel attached to the rescue hoist cable.

The grapnel shown was mocked up using an original sinker weight, to which were secured wooden grapnel hooks and a metal fin to stabilize it in flight. The helicopter tanker trailed two lengths of Mk 20 (1.5 inches, 38 mm, bore) type refuelling hose joined together with a paradrogue attached to the trailing end, as shown below, to create a catenary.



Mock-up grapnel



Wessex helicopter trailing hose

The tanker flew straight and level while the receiver flew above and astern and crossed from starboard to port collecting the hose within the grapnel hooks. As shown, it was found possible to make a contact.



Wessex helicopters in contact

The trials were considered to be reasonably successful in that several contacts were made, after which the two helicopters had to land linked together. But the conclusion was that the system would require a lot more development, and it was abandoned.

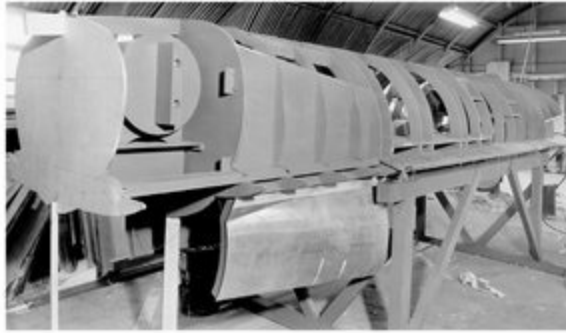
The new TSR-2 being designed by Vickers Armstrong at Weybridge, Surrey, and English Electric at Warton, Lancashire, in 1961 had a requirement for a tanker version to refuel the standard aircraft. The refuelling equipment was again to be a package, which would be installed within the aircraft's bomb-bay as alternative-role equipment.

Flight Refuelling Ltd conceived the Mk XXVI refuelling package, which was to carry out refuelling at Mach 0.90, or 350–400 kts IAS at 33,000 feet (10,154 metres), with the capability of transferring fuel at 300 imperial gallons (1,350 litres) per minute, and to have 450 imperial gallons (2,025 litres) of disposable fuel within the package's fuel tank. Owing to the aircraft's high angle of attack in the refuelling envelope to ensure that there was sufficient vertical separation between the two aircraft, the package incorporated a retractable boom, which provided a nominal 12-foot (3.72 metres) separation, as shown in [Fig 43](#) to which could be added the refuelling hose catenary.

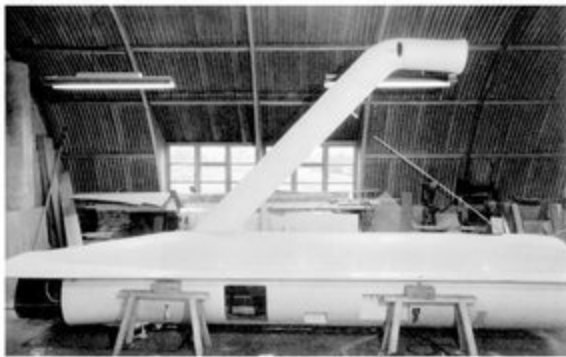
A full-sized mock-up of the complete package being built are and the completed mock-up shown on the right.

The hose-drum unit was similar to that of the Mk XXI, and was located at the forward end of the package structure within its own bay. The boom was pivoted just aft of the unit in a separate bay, the latter having a narrow slot running aft to accept the boom when retracted.

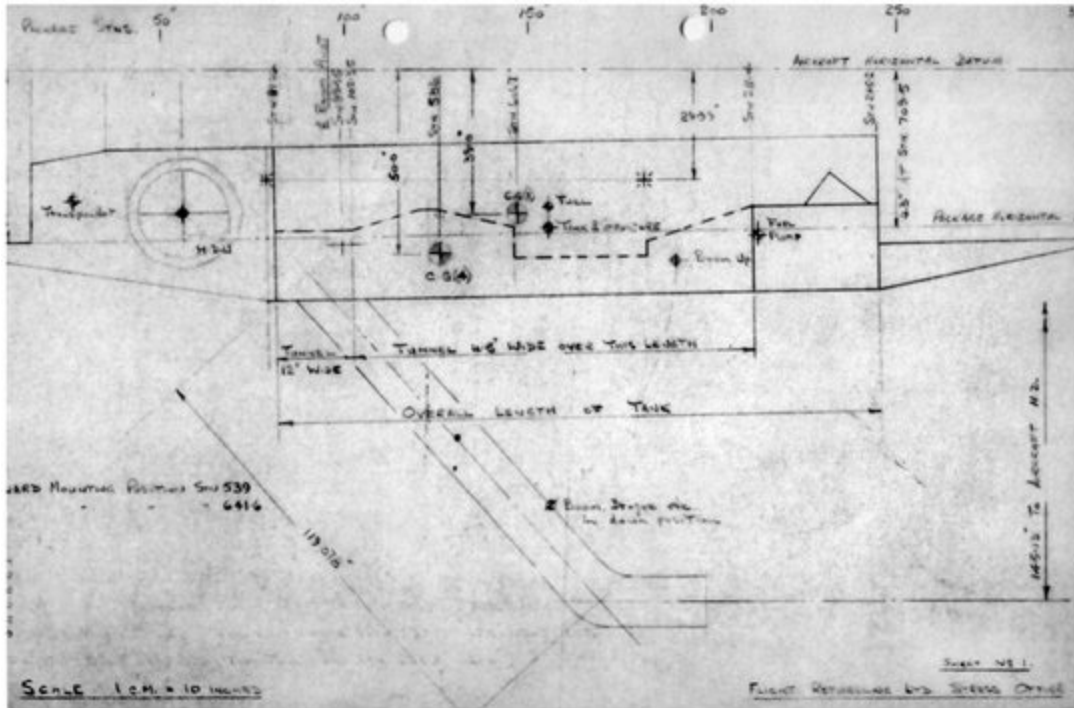
[Fig. 43](#). Outline drawing of Mk 26 refuelling package



Building Mk 26 refuelling package mock-up



Mock-up of Mk 26 refuelling package



The prototype hose-drum unit and the boom were to be installed in Canberra WH.734 for the initial flight development trials, and the design of the installation was virtually completed

The completed mock-up was installed in the TSR-2 mock-up to confirm all of the necessary electrical, fuel and hydraulic interfaces, together with the logistics of ground handling.

However, with a large portion of the design completed, like the Buccaneer project the whole programme was cancelled. Nevertheless, Flight Refuelling Ltd had gained further experience and knowledge in higher airspeeds of refuelling.

The Armstrong Whitworth Division of Hawker Siddley Aviation, together with Flight Refuelling Ltd, carried out a design feasibility study for the then Ministry of Aviation in January 1963, for the conversion of the Argosy C Mk 1 freighter aircraft of the Royal Air Force into a tanker and receiver. A further meeting with the Ministry took place in

January 1964 to discuss the proposal derived from the feasibility study to convert the aircraft. It was agreed that the conversion of one tanker and receiver should be carried out for trial purposes.

The feasibility study produced two alternatives for the conversion of the tanker. The first was by the incorporation of three Flight Refuelling Ltd Portable Overload (POL) fuel-tanks located in the aircraft's fuselage, which would supply a variant of the Mk 20 series of refuelling pods. This pod was to be mounted on a pylon attached to the aircraft's fuselage forward of the port parachute door, as shown here.

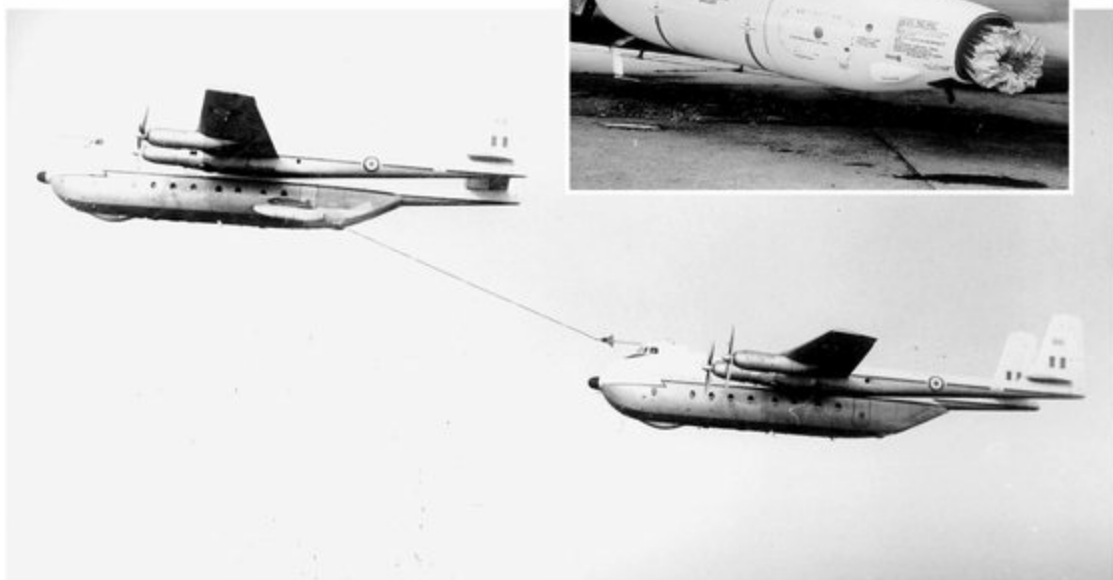
The second proposal employed the same installation for the refuelling pod, which, due to the installation, required some modification and was designated as the Mk 20D refuelling pod. However, this proposal was to make use of four standard overload fuel tanks also to be installed within the aircraft's fuselage.

The first proposal would provide 2,190 imperial gallons (9,855 litres), the fuel being pumped from the POL tanks to a main delivery pump, and thence to the pod. The second, with the four standard overload tanks, provided a total of 1,720 imperial gallons (7,740 litres), the existing submerged fuel pumps within the tanks having been removed.

The two aircraft involved in this trial were XN.814 as the tanker and XN.816 as the receiver, as shown below.

The trials were successful using the modified refuelling pod. But once again these two aircraft were the only ones modified, and the project was cancelled. However, regardless of the Argosy programme, Flight Refuelling Ltd was busy with the design of equipment for the new Victor tanker.

Argosy Mk 20D refuelling pod installation



CHAPTER THREE

The Achievements, 1965-93

In 1965 the Engineering Department of Flight Refuelling Ltd moved to the new factory premises at Leigh Park, Wimborne, Dorset, as shown below.

The company was still involved with the development of the new Victor three-point tanker and assisting the Royal Air Force with the new equipment. Work was also proceeding at Handley



Flight Refuelling Ltd's Wimborne Factory, Dorset, 1965

Page Ltd at Radlett on the conversions.

In July 1966 No. 214 Squadron, whose Valiants had pioneered the flight refuelling techniques in the Royal Air Force, was reformed at Marham, and it received its first three-point tanker in September 1966. Completing the Marham Wing, No. 55 Squadron re-equipped with Victor K1A three-point tankers early in 1967, and a tanker training flight was set up at Marham flying K1s and K1As, with a supporting air refuelling school.

It was decided to carry out all Victor Mk 1 training at one location, and so the Mk 1 ground school moved from

Finningley to Marham, where it joined the flight simulator, AAR school and tanker training flight to become the Victor OCU on 13 October 1969. On 6 February 1970 the unit assumed the title of No. 232 OCU, and was equipped with three Victor B1s and two Victor B(K)1As as two-point tankers. At this time the OCU's task was limited to aircraft type conversion, role training being carried out on the operational squadron after the crew had completed an introduction to the AAR school. The tanker force was originally under the operational control of No. 3 Group, which was responsible to Bomber Command for operations and training, but since 1968 this control had been exercised by No. 1 Group of Strike Command, and detailed planning for refuelling exercises was the responsibility of an AAR Planning Cell at No. 1 Group.

During the 1960s the Victor tanker force built up considerable experience in the role of supporting the operations and deployments of the RAF's shorter-range combat aircraft, both in the NATO area and world-wide, a role that assumed greater significance as the Royal Air Force's permanent bases overseas dwindled.

In 1967 Lightnings were deployed to Tengah, Singapore, and trials were carried out with F-4 Phantoms at Edwards AFB in the USA. In 1968 Royal Navy Sea Vixens were deployed to Akrotiri and Buccaneers to Muharraq and Changi. Tankers were used in May 1969, both by Royal Air Force Harriers and Royal Navy F-4 Phantoms in the Daily Mail Transatlantic Air Race. As a reward these crews deployed Lightnings to Darwin the following month, and the Victor completed its first Pacific Ranger (trans-Pacific training flight) in August 1969. In September of that year a Victor took part in the first long-range interception of Russian aircraft.

In December 1969 ten Lightnings were deployed to Singapore, typically shown refuelling from the Victor's fuselage position.



Lightning refuelling from Victor's fuselage unit

They were refuelled thirteen times from Victors staging out of Marham, Akrotiri, Masirah and Gan, returning via the same route a month later after air defence exercises. Fighters from the United Kingdom could reach Cyprus in four and a half hours, and the Arabian Gulf in eight hours. Two F-4 Phantoms flew non-stop to Singapore in a world-record time of 14 hours 8 minutes. Air defence of the fleet could be maintained, and simulated attacks on shipping could be carried out. Victors and Lightnings took part in the 50th Anniversary of the Royal Australian Air Force in April 1971, and the following month Marham was proud to host HRH Princess Margaret on a visit. By 1972 the tanker force was visiting Tengah monthly, and accompanied Buccaneers to Tai Mo Shan, Hong Kong.

In comparison with the eighteen months of the two-point tankers, fuel transfers of 6,000,000 lb, or 750,000 imperial gallons, were achieved in September 1972. No. 55 Squadron transferred 2,500,000 lb, or 312,500 imperial gallons, of fuel during 478 hours' flying, including the delivery of the last production Lightning from Warton, Lancashire, to Khames Mushayt. The rapid deployment force was exercised in July 1974 when twelve armed Phantoms deployed to Cyprus overnight and were operational the following morning, during the Turkish invasion.

Operations with the Victor K1 and K1A aircraft during the 1960s and early 1970s had revealed a requirement for a K2 variant with a longer range, increased power and a greater fuel uplift, especially when operating from airfields at high altitudes in hot climates. Late in 1968 it was decided to convert either B2R XM.175, which had sustained wing-root damage and was in storage at Radlett, or XL.614, which was at St Athan, to a K2 standard for trials. These were to be followed by twenty-eight further conversions, which were to include No. 543 Squadron's Victor SR2 fleet.

This requirement was later modified to twenty-one, with some K1As retained in service.

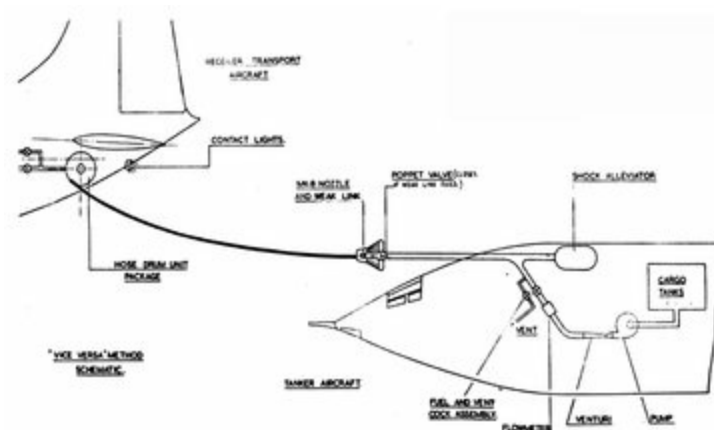
It was originally planned that the K2s would enter service in 1973, but the conversion programme was subjected to serious delays by Handley Page's financial problems. Although HP did all the design work, the company never received a contract and it closed in February 1970. Later that year Hawker Siddeley Aviation won the contract, and the surplus B2Rs were transferred to Chadderton and Woodford.

While the RAF was achieving great success with its operations, Flight Refuelling Ltd was still busy with proposals and new ideas to simplify not only the equipment but the technique of air refuelling for the larger transport aircraft through the 1960s.



Victor refuelling Buccaneers

Fig. 44. Vice versa air refuelling



In March of 1966 an investigation into reversing the roles of tanker and receiver aircraft was made. The following describes how this, which was termed the 'Vice Versa' method of air refuelling, could be achieved for large transport aircraft. It is shown in Fig 44.

The need to refuel transport aircraft such as the Armstrong Whitworth Argosy, the Short Belfast, the Lockheed C-130 Hercules and the Vickers VC10 introduced problems as compared with bomber and fighter aircraft.

In the orthodox air refuelling system, the tanker flew straight and level, while the receiver pilot manoeuvred his aircraft into position, made contact and then flew in formation. In this system the roles were reversed, and the tanker would be flying behind the receiver, which would be trailing the hose and drogue, while the tanker formatted and pumped the fuel via its probe. This is fully described in the technical section. However, no interest was shown, even though it would help the pilots of large transport aircraft.

The American Navy was having serious problems in 1969 with its D704 air refuelling pod; it therefore raised a requirement for the investigation of a mechanically operated hose-drum unit.

The traditional method of achieving a substantially constant tension in the refuelling hose for a hose-drum unit was to provide power to it via a hydraulically powered hose-drum system. In this method of powering, a proportion of failures in service arose from failures within the hydraulic system and failures of the power source, the former due to the number of components required for the system.

Flight Refuelling Ltd took up the challenge to investigate a simpler method, whereby a hose-drum unit could be embodied within a self-contained pod, and be operated by a simple mechanical spring system without external power or hydraulic transmission for the refuelling hose response when a contact was made by a receiver.

The requirement issued by the American naval authorities was a large specification which Peter MacGregor, the chief designer of Flight Refuelling Ltd, studied together with myself, and after some early investigation he decided it was a feasible requirement. However, during the investigation I concluded that if the company agreed to carry out a deeper investigation, whatever successful conclusion was reached the rights of the design could belong to the American Navy.

MacGregor and I discussed this possibility with the then

technical director, A.W. Goodliffe, and he commented, 'Get going on a design, and when completed we will patent it.' This resulted in a very deep study being made, which eventually conceived the Mk 32/2800 refuelling pod.

The initial concept was based on the Mk 20B refuelling pod's known performance using what was termed a fuelhydraulic power system for trailing and winding the refuelling hose, and a 'Tensator Spring Motor Unit' for the hose response when a receiver made a contact. The fuelhydraulic power system derived its initial power from a ram air turbine driving a fuel pump taking fuel from the pod's fuel system, which was required for two operations of the pod—firstly to pump the fuel from the tanker aircraft to the receiver aircraft, and secondly to provide the power to a motor/pump unit in the motor mode to rewind the refuelling hose, the fuel flowing in one closed-loop system. To trail the hose all that would be required was for the hose-drum brake to be released, the drogue and reception coupling being ejected into the airstream and the drag of the drogue pulling the refuelling hose off the hose drum, thus driving the motor/pump unit as a pump with the fuel in a second closed-fuel-loop circuit. The trailing speed of the refuelling hose was controlled by a fuel control valve, thus requiring no power from the fuel pump.

For the refuelling hose response when a receiver made a contact, the tensator spring motor unit provided a virtually constant hose tension load over the operational requirements of receiver manoeuvrability, once engaged. This system is shown diagrammatically in [Figs 45, 46](#) and [47](#).

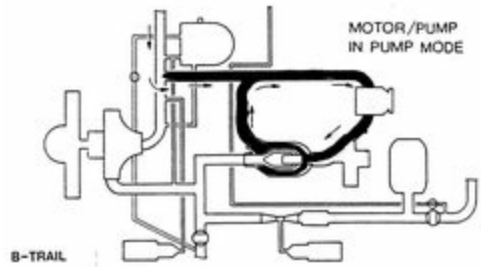


Fig. 45. Mk XXXII sytem trailing mode

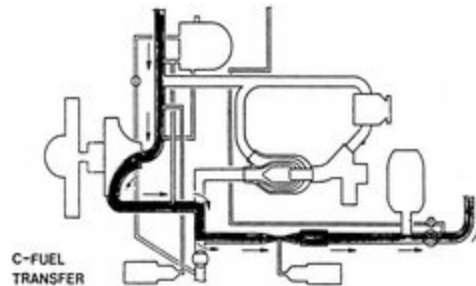


Fig. 46. Mk XXXII system fuel transfer mode

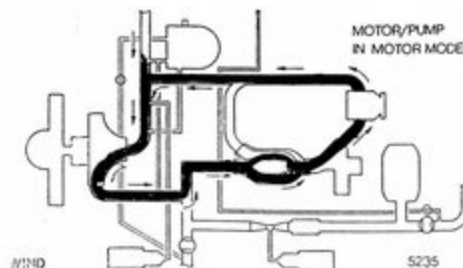


Fig. 47. Mk XXXII system wind mode

Nevertheless, with the basic idea having been conceived and a world-wide patent being applied for, it still took several years for the Mk 32 refuelling system to become an operational piece of equipment. The detailed development of the new system is described under the Mk XXXII refuelling pod, but I feel that some explantion of it is required in these pages.

One of the original ideas, of basing the system on the Mk 20B pod performance, especially the fuel transfer flow rate, did not create much interest in the new system. And the question of who would pay for the development costs arose, as the Services were satisfied, particularly with the existing British refuelling equipment.

After much discussion it was concluded that at this time no serious development was required for the transfer and control of the fuel, as Flight Refuelling Ltd was very experienced in this field. However, the major development was considered to be with the 'Tensator Spring Motor Unit', as nobody had employed the springs in such a system.

A test rig was built at Tarrant Rushton in order to develop the tensator system and prove its capabilities. The rig included a simulated fuel system, and the motor/pump unit was a borrowed Dowty fuel system vane-type fuel proportioner unit. After a period of time the system was found to be very successful, and it provided the necessary refuelling hose response.

As previously mentioned, the proposed fuel transfer flow was not received with any great enthusiasm, particularly as future receiver aircraft were to have a higher acceptable fuel flow rate, thus reducing their time in contact. It was therefore decided to increase the transfer flow rate to 350 imperial gallons (1,575 litres) per minute. With this new concept, the new refuelling pod was now designated as the Mk 32/2800, the latter part designation being the flow rate in pounds. This new performance required a new fuel pump and ram air turbine, resulting in technical discussions having to be made with Mr John Thompson of the Plessey Company at Titchfield, Hampshire, for the fuel pump, and Mr Phil Morris of Dowty Rotol at Cheltenham, Gloucestershire, for the new ram air turbine.

Eventually the newly designed prototype refuelling pod was manufactured and ground tested in the test house at

Wimborne.

During the long period of development a new tanker requirement arose, as the Royal Air Force required an increase in its tanker fleet. The Vickers VC10 civil airliner was chosen to be converted, after a design study had been carried out in 1977. In the study the Mk XXB and the Mk XXXII types of refuelling pod were given as an option for installation at the wing stations, the reason for including the option being that the latter equipment was still under development.

de Havilland FAW Mk I Sea Vixen XJ.580



To enable Flight Refuelling Ltd to carry out contractor's prototype flight testing of the Mk XXXII pod; a de Havilland FAW Mk I SeaVixen XJ.580 was allocated to the company. The installation of the pod to the aircraft's starboard outer wing pylon is shown below.



de Havilland Sea Vixen FAW Mk I XJ.580 pod ground clearance



de Havilland Sea Vixen FAW Mk I pod door clearance

The photographs of the refuelling pod show the small ground clearance that was available, and the minimal clearance between the pod and the aircraft's undercarriage door.

The first prototype pod flight test took place out of Hurn Airport, Bournemouth, on 23 December 1980, the Sea Vixen being piloted by Mr D. Ashover AFC, together with Mr R. Henson as the flight test observer. During this flight problems arose with the trailing and winding of the refuelling hose, which finally ended with the refuelling hose remaining partially trailed; the aircraft having to make an emergency landing at A&AEE Boscombe Down. All further flight tests were then carried out at Boscombe Down, and these initially comprised trailing and winding the refuelling hose through the speed and altitude ranges. They were also accompanied by a Boscombe Down chase aircraft to observe and film the operations. On the completion of numerous satisfactory flights, they were followed by dry contacts, again through the speed and altitude ranges, and these

proved the tensator spring motor's providing the necessary hose response when a contact was made. It also proved that with this method of hose response a higher receiver aircraft overtaking speed was acceptable. However, during this phase, when an in-flight refuelling was selected in the Sea Vixen, it automatically transferred the internal fuel from the port wing tanks to the starboard (this was normal for a Sea Vixen tanker conversion), and the aircraft's starboard wing became heavier than the port as no fuel was being passed to a receiver. It was therefore necessary for the pilot to carry out a revised fuel drill in between contacts to balance the aircraft.

These flights were followed by a receiver making wet contacts to prove the total system, and a high rate of flow was achieved with the Phantom receiver where the fuel pressure at the reception coupling fell below the nominal 50 psi (3.4 bar). Nevertheless, all flights were satisfactorily completed, and the next phase was the flight testing of the pre-production version of the pod on the new Vickers VC10 three-point tanker.



Vickers VC10 three-point tanker

Conversion of the VC10 commercial airliner into a three-point tanker commenced at Filton, Bristol, in April 1978. The conversions totalled nine aircraft, five Standard aircraft being designated as K Mk 2 and four Super aircraft

designated as K Mk 3. Each aircraft was to have three refuelling hose-drum units, one beneath each wing, and one in a specially constructed bay in the underside of the rear fuselage. A typically converted aircraft is shown above refuelling an F-4 Phantom.

The following is a brief history of the nine aircraft conversions:

Vickers Type	Civil Registration	First Flight	Delivery Date	Airline	RAF Tail No.	Tanker Mark
1101	G-ARVL	02-06-64	16-06-64	BOAC/BA Gulf Air	ZA.140	K Mk 2
1101	G-ARVG	17-09-63	12-06-64	BOAC/BA Gulf Air	ZA.141	K Mk 2
1101	G-ARVI	20-12-63	22-04-64	BOAC/BA Gulf Air	ZA.142	K Mk 2
1101	G-ARVK	28-03-64	02-05-64	BOAC/BA Gulf Air	ZA.143	K Mk 2
1101	G-ARVC	21-03-64	01-12-64	BOAC/BA Gulf Air	ZA.144	K Mk 2
1154	SH-MMT	12-10-66	31-10-66	East African Airways	ZA.147	K Mk 3
1154	SY-ADA	21-03-67	31-03-67	East African Airways	ZA.148	K Mk 3
1154	SX-UVJ	19-04-69	30-04-69	East African Airways	ZA.149	K Mk 3
1154	SH-MDG	16-02-70	28-03-70	East African Airways	ZA.150	K Mk 3

The five Standard aircraft were originally Vickers type 1101 for British Overseas Airways, and subsequently operated by Gulf Air of the Middle East, while the four Super aircraft were Vickers type 1154 operated by East African Airways.

The three-point concept was to employ the Mk XVIIB refuelling package as used in the Victor K Mk 2 at the centre-line or fuselage position, and either the Mk 20B or the new Mk XXXII refuelling pod at the wing stations. The overall installation was also to have additional fuel tanks to augment the aircraft's existing fuel capacity.

The installation of the Mk XVIIB is shown below, viewed from astern on the aircraft's port side, showing the drogue

stowage tunnel, contact lights and under-wing lighting. The Mk XXXII refuelling pod, having completed its development trials, was eventually chosen for the aircraft's wing stations, as shown opposite on the port wing and from astern, showing the stowed drogue and contact lights.



Vickers VC10 Mk XVIIB rear fuselage installation



Vickers VC10 Mk XXXII pod port wing installation



Vickers VC10 rear view of Mk XXXII pod

The prototype VC10 K Mk 2 three-point tanker made its maiden flight on 22 June 1982 from Filton, which was an initial handling flight to determine if there were any problems caused by the addition of the in-flight-refuelling installations. However, early flight-testing problems did arise with the wing pylon's electrical butt connectors to the Mk XXXII refuelling pod.

The connectors were identical to those used on all the Mk XX series of refuelling pods, although intermittent problems had occurred. The problem with this installation was that during flight the connectors became intermittently separated between the pylon sole-plate and the pod, thereby braking the electrical supplies to the pod. It upset the pod's electronic logic system, causing the pod not to respond to the operational sequences selected by the operator. During the debriefing of this particular flight, the following comment was made: 'The pod has a mind of its own, doing whatever it wants to do regardless.' Nevertheless, the problem was soon overcome by deleting the butt connectors, and replacing them with plugs and sockets on flying leads, and no further problems arose thereafter. During one

further flight trial a landing was made with the refuelling hose on the starboard wing trailed. On all previous hose-drum units when carrying out this procedure the refuelling hose would remain at the full trail. However, the Mk XXXII pod incorporated a tensator spring motor, which would automatically rewind the hose once the tanker's landing speed was reduced during the landing run, owing to the drogue drag being reduced. The following photographic sequences show, the tanker aircraft flying overhead with the hose fully trailed; and the aircraft landing with hose trailed; and above the refuelling hose winding in as the aircraft's speed is reduced.



Vickers VC10 K Mk 2 trailing Mk XXXII pod hose



Vickers VC10 K Mk 2 landing with wing pod trailed



Vickers VC10 K Mk 2 hose rewind on landing

On inspection after the landing event, it was found that the equipment had suffered minimal damage, enabling it to be reused.

The prototype flight trials, including those of the parent company and A&AEE Boscombe Down, continued through 1982 until mid-1983, when Boscombe Down gave the necessary clearance for service use.

On 25 July 1983 at the handing over ceremony at Filton, Air Chief Marshal Sir David Craig (later to become Chief of the Defence Staff during the Gulf War) accepted the first production VC10 K Mk 2 tanker ZA.140 for the Royal Air Force, and after the ceremony it flew to RAF Brize Norton to commence operations with 101 Squadron.

The United States of America was still having problems with its probe and drogue equipment in 1980. The Grumman Aerospace Corporation and Flight Refuelling Ltd agreed to have discussions on combining their experience in the field of air refuelling. On 15 January 1981 they signed a memorandum of understanding to cooperate in the design and manufacture in an unsolicited proposal for a new refuelling pod for the United States Navy. It was also agreed that the proposal should be led by Grumman Aerospace at Bethpage, Long Island, which would submit the proposal to

the naval authorities in Washington DC.

The proposed pod was to be a derivative of the VC10 32/2800 wing pod using the innovative fueldraulic system to power the hose-drum unit, and it was given the designation Mk 35/2800.

The overall design was to employ the three-modular concept, viz. a forward section which would incorporate the power unit (ram air turbine and fuel pump), a centre section comprising a fuel tank with the necessary fuel system components and aircraft interfaces, and then the aft section containing the hose-drum unit, drogue-stowage tunnel and contact lights. The breakdown of the design and manufacture was to be divided between the two companies in the following manner: Grumman Aerospace would be responsible for the design and manufacture of the centre-section fuel-tank, and Flight Refuelling Ltd for the forward-section power unit, and the aft section with the hose-drum unit. The final assembly of the three sections, together with ground and flight testing, would be undertaken by Grumman Aerospace at its facility at Bethpage. On the completion of the ground testing it was proposed to flight test the pod on a Grumman A6.E aircraft, during which the flight speed and altitude envelope, together with fuel transfers, would be carried out.

The Mk 35/2800 refuelling pod is illustrated below, and [Fig 48](#) shows its position on the Grumman A6 aircraft.



Grumman/Flight Refuelling Mk 35/2800

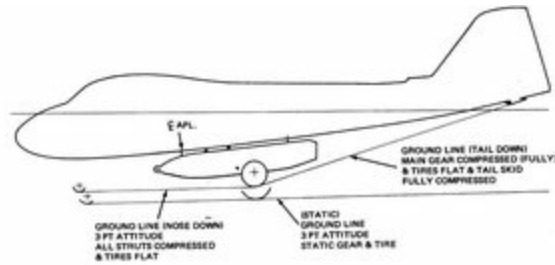


Fig 48. Grumman A6, showing Mk 35/2800 pod position

And [Fig 49](#) illustrates the modular breakdown of the refuelling pod.

The division of the Grumman/Flight Refuelling Ltd responsibility for the design and manufacture of the refuelling pod has been described earlier. However, the management of the project, especially when consideration is given to the long distance that separated the two companies, has to be mentioned, showing how the cooperation was to be organized.

As prime contractor to the American naval authorities, Grumman Aerospace offered a broad background in American naval aircraft design, manufacture and support, through an understanding of aircraft refuelling interface requirements for both tanker and receiver aircraft. It had incorporated air refuelling equipment in the A6 attack aircraft, the EA6, E-2 and F.14 (Hornet), and had modified the A6 attack aircraft into a KA-6D tanker. As a result Grumman was also experienced with aircraft ground servicing equipment requirements, and had experienced personnel on American Navy aircraft-carriers, and at naval land-based depots world-wide.

Grumman Aerospace was a subsidiary of the Grumman Corporation and was led by Mr G.M. Skuria, the chairman and president of the company. The design and development of the refuelling pod was to be the responsibility of the company's development department, which was led by Mr T. Kane and Dr Caparoli, both of whom were vice-presidents,

Flight Refuelling Ltd was a subsidiary of Flight Refuelling Holdings Ltd (now the Cobham Group) under the chairmanship of Mr (later to become Sir) Michael Cobham, and was managed by Mr K. Coates, the managing director, who was also a director of the Holdings company. The design and development of the in-flight-refuelling equipment was carried out within the military systems division of the company, which at the time of the Grumman/Flight Refuelling agreement of 1981 was managed by Air Commodore G. Goodyer RAF (Rtd) and Mr J. Medget as the engineering manager. Included in the design team were myself as senior project engineer (design), Mr R. Henson, senior project engineer (development), and Mr D. Lloyd, senior project engineer (design electrical).



The commercial business, together with cost control, was

managed by the late Mr T.C. Marks (commercial director), and Mrs C. Martin, the contracts manager.

To enable a single line of contact to be maintained between the two companies, Mr Medget of Flight Refuelling and Mr I. Henriksen of Grumman Aerospace were made programme managers for the respective responsibilities of the project, and both of them could be in communication on a day-to-day basis.

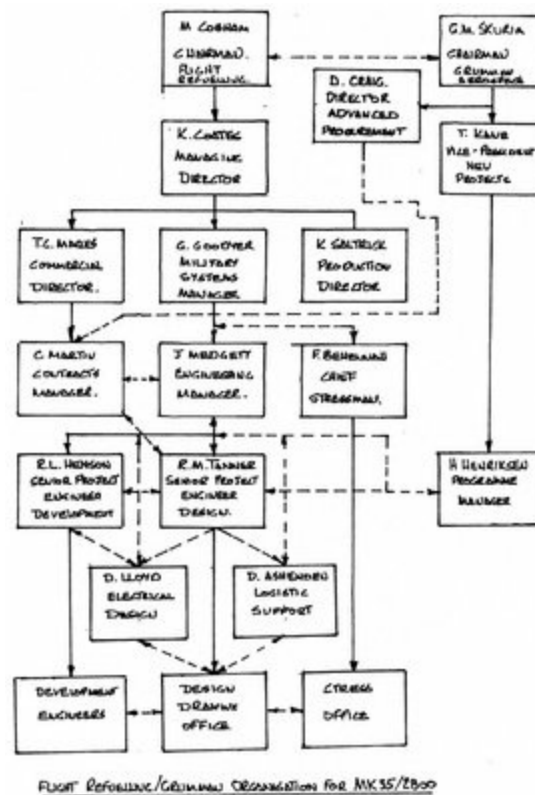


Fig. 50. Mk 35/2800 refuelling pod management

However, after Mr Lloyd and I had spent some three months at Grumman Aerospace, Bethpage, assisting with the proposal for the unsolicited bid, no agreement for the design and manufacture was achieved.

Nevertheless, in 1985 a formal request from the American naval authorities was made for a new refuelling pod.

Prior to this an organizational change within Flight Refuelling occurred, when Mr F. Behennah became the technical director, and therefore responsible for the military systems division; Mr Medget was no longer the engineering manager, as he was responsible for the new CAD-CAM design system; and Mr T. Woodcock had become the engineering manager. The late Mr Marks, the commercial director, had retired from the company, being replaced by Mr R. Clark, and Mrs Martin remained as the contracts manager.

The communication between the two companies was similar to that in the previous unsolicited bid, using the same format as shown below.

Grumman and Flight Refuelling welcomed the opportunity to provide a new, yet proved refuelling pod through a minimal-cost programme. Both companies were anxious to demonstrate that reliable aerial refuelling could be accomplished with low life-cycle costs with traditional quality. This could be demonstrated in depth since the Falkland Islands Operation Corporate, which showed the high reliability of the Royal Air Force's aerial refuelling equipment; and the proposed programme would be in keeping with the letter and spirit of cooperation between the governments of the United States of America and Great Britain.

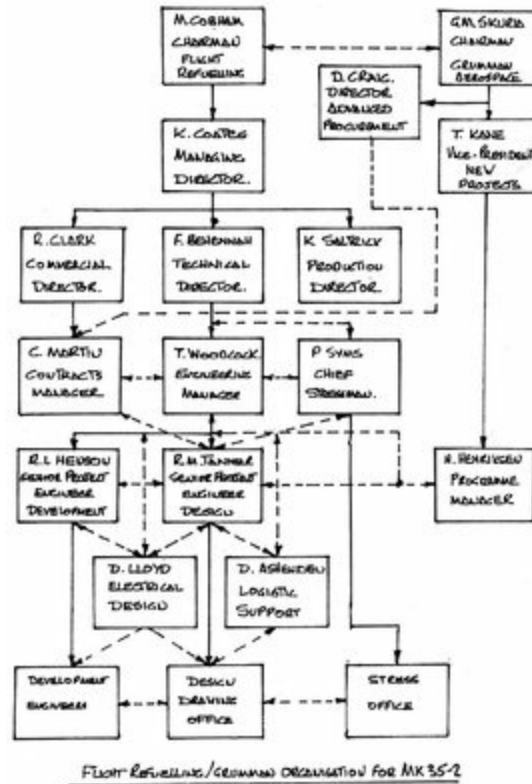


Fig. 51. Mk 35-2 refuelling pod management

Once again Mr Lloyd and I travelled the Atlantic to Grumman Aerospace at Bethpage, again to assist in the compilation of a proposal with the Grumman design engineers. The refuelling pod was now designated as the Mk 35-2, which incorporated further improvements to the overall system, and included a revised profile to conform with the existing American D.704 naval refuelling pod.

To illustrate the shape, the basic lines diagram is shown in [Fig 52](#), and the overall assembly in [Fig 53](#).

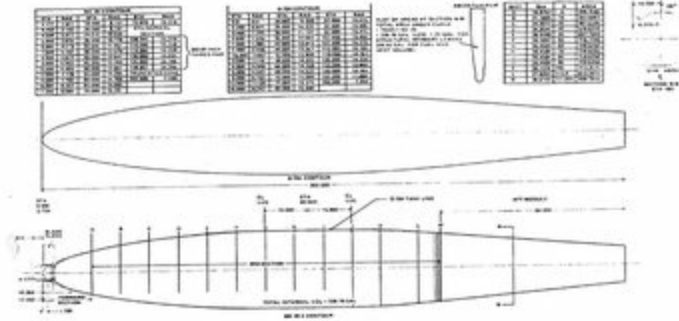


Fig. 52. Mk 35-2 refuelling pod lines

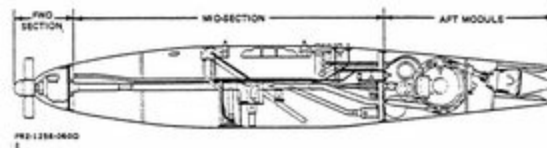


Fig. 53. Mk 35-2 aerial refuelling pod

With the refuelling pod's shape revised, the aerodynamic characteristics were known, and so the cost of design and flight testing could be reduced, particularly in the latter case, as it was usual for new equipment to be exhaustively flight tested on each aircraft to which it was fitted.

Similar to the Mk 35/2800, the Mk 35-2 was also to be designed with the three-module concept.

However, although the responsibilities were similar, Flight Refuelling Ltd owned the patent rights of the system, both in the United States of America and in Great Britain. As this was now a formal proposal, the original memorandum of understanding between the two companies for the unsolicited bid of the Mk 35/2800 now required some further clarification. Flight Refuelling Ltd therefore agreed to grant to Grumman Aerospace

- a. The exclusive right and licence to develop, and manufacture and test the Mk 35-2 refuelling pod in the United States of America, this for the sole purpose of

- supplying it to the United States Government, and
- b. the exclusive right and licence to use the patents throughout the United States or government sites or installations outside continental United States to provide in-service support of the Mk 35-2 refuelling pod to the United States Government.

The forward module was similar to that of the Mk 35/2800, and was the responsibility of Flight Refuelling Ltd, though the front fairings were to be designed by Grumman. The centre module comprising the fuel tank was also still the responsibility of Grumman. The design of the rear module, containing the hose-drum unit, reception coupling and drogue, and contact lights, remained with Flight Refuelling Ltd.

However, once again, after a very large effort by both companies and the reports on the Falkland Island conflict showing the success with the British in-flight-refuelling equipment, nothing was achieved from the formal proposal.

On 2 April 1982, the military forces of Argentina invaded the Falkland Islands in the South Atlantic Ocean. The closest British territory was Ascension Island, which is 3,900 miles to the north of the island's main town of Port Stanley, having only one air base on its barren landscape. The only method to bridge this large gap to support any future British landings was by the use of in-flight refuelling using the Royal Air Force's tanker fleet. This at the time comprised the Handley Page Victor K2 three-point tankers.

Victor 2 refuelling F-4 Phantom



Training of the squadrons commenced immediately for maritime reconnaissance, and three aircrews were selected initially to practise low-level reconnaissance making simulated attacks on islands and airfields in Scotland. However, during this period modifications were made to the tankers by the incorporation of nose-mounted cameras and improvements to the radar 'Carousel' inertia navigation equipment, this later being replaced by 'Omega' inertia navigation equipment.

The advance party from RAF Marham for what was now termed Operation Corporate arrived at Wideawake air base on Ascension on 18 April 1982, followed by the first of the Victor tankers. The initial task for these was radar reconnaissance to cover the area around South Georgia and the coastline of Argentina, and surveillance of the seaway ahead of the task force now en route from the United Kingdom. Several night-time refuellings were carried out, the first surveillance lasting for 14 hours 40 minutes, with further surveillance taking place during the following week. By 28 April virtually three-quarters of the tanker fleet was dispersed to Ascension, and although a further nine Vickers VC10 aircraft were in the process of being converted into three-point tankers, they would not become available for this operation, and so there was now an urgent requirement for more tanker aircraft. Also, as the British Aerospace Nimrod surveillance and Lockheed C-130 Hercules transport aircraft were now incapable of being flight refuelled, urgent

modifications were carried out to incorporate the necessary refuelling probe to them, these modifications being carried out within two weeks of the initial order being placed. The first long-range operational air refuelled flight by a Hercules was made by Flight Lieutenant Harold Burgoyne of No. 47 Squadron on 16 May, with a journey to the Total Exclusion Zone that had been imposed round the Falkland Islands. This first flight covered 7,247 miles in 24 hours 5 minutes. Likewise, to introduce new tanker aircraft, the Avro Vulcan bomber and the Lockheed C-130 Hercules aircraft were converted into single-point tankers in the space of six weeks. The former was to supplement the United Kingdom's defence operations, and the latter to support other Hercules on Ascension.

The following figures illustrate the Avro Vulcan B.1 and Lockheed C-130 Hercules tanker conversions, together with the Hercules refuelling probe.

It was obvious that Operation Corporate would be given the highest of priorities, and should any problems occur with the airborne refuelling equipment or system, this would require an urgent response from the parent companies of the particular equipment. To cover this contingency, the then technical director of Flight Refuelling Ltd, Mr F. Behennah, organized a small team of people for any such occurrence. The team would be available to assist and be on call at any time, and it would be capable of providing the necessary design information should any further conversions of aircraft into tankers or receivers become urgently required. The team comprised myself, Mr D. Ashenden (logistic support manager), Mr R. Young (project engineer, design), Mr D. Stagg (senior design draughtsman), Mr D. Preston and Mr P. Collier, the latter two heading a works team who became engaged in the assembly and testing of the refuelling equipment and system components.



Avro Vulcan tanker refuelling Avro Vulcan B.1



Lockheed C-130 Hercules refuelling Nimrod aircraft



Avro Vulcan tanker drogue stowage



Lockheed C-130 Hercules receiver probe

With the Task Force now en route to the South Atlantic, the Royal Air Force at RAF Waddington in Lincolnshire was busy preparing the Avro Vulcan B.2 bombers of No. 50 Squadron for long-range operations. One of the major tasks was to reactivate the aircraft's in-flight-refuelling system, which had not been used for fifteen years. When the reactivation had been completed, it was found during the initial flight testing that when a contact was made with a tanker, a severe splash of fuel occurred, which covered the aircraft's windscreen, causing what was termed a 'white-out'. This was quickly overcome, having been sorted out by Mr Ashenden and myself, who were flown from Hurn Airport, Bournemouth, to RAF Waddington in an RAF helicopter on a Sunday morning. This was the only major problem that arose with the equipment in England during the initial Falkland Islands operation.

With the Vulcan problem resolved, it was later learnt that the first bombing raid on the Port Stanley air base was carried out on 1 May 1982. The operation, coded Black Buck 1, was achieved in less than one month after the invasion by Argentina, and a fortnight after the Vulcan aircrews had recommenced their in-flight-refuelling training. The aim of the raid was to prove that the mainland of Argentina was within bombing range, and more importantly to deny the

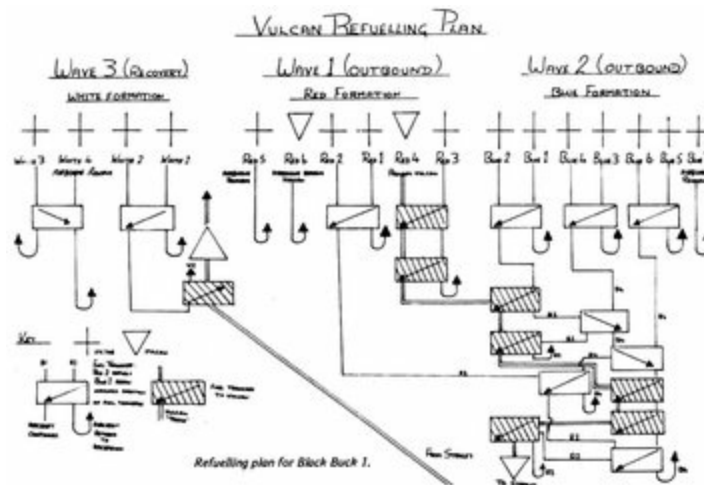
enemy the use of the runway at Port Stanley air base. Ten Victor tankers were used to refuel two Vulcans. This was in the initial planning, but one of the Vulcans was included as a reserve, and in fact took no part, but returned to Ascension. The planned operation was to refuel the Vulcan five times at night in the event that a further refuelling became necessary because of the higher than anticipated consumption of fuel. [Fig 54](#) illustrates the overall plan of the operation where the second Vulcan was acting as a reserve. Nevertheless, the best of well-laid plans incur incidents that cannot be accounted for. Such a one occurred some 2,750 miles south of Ascension Island when Squadron Leader Bob Tuxford and Flight Lieutenant Briglands were piloting Victors XL.189 and XH.669, the two remaining tankers accompanying Flight Lieutenant Withers in Vulcan XM.607.

It was time for Tuxford to transfer fuel to Briglands' Victor to enable him to continue with the Vulcan to within 300 miles of the target. However, in very turbulent conditions the refuelling nozzle of Briglands' probe snapped off, whereupon the two pilots agreed to exchange their roles. Tuxford then took on the fuel required to fly with the Vulcan, and Briglands altered course back to Ascension. Further problems arose due to the fact that when the two aircraft had changed their roles, their call signs had not been properly exchanged, which resulted in both aircraft on their return flight giving out the same identification signals.

Squadron Leader Ernie Wallis told how, when it became possible to send a transmission, Briglands was stating that there were no problems with his aircraft, while Tuxford was having a problem, having passed more fuel to the Vulcan than had been planned, and he was short on fuel to return to Ascension Island. However, the mission was completed successfully as Tuxford was able to meet another Victor some 600 miles south of Ascension with thirty minutes of fuel remaining prior to the contact. Fortunately this incident occurred after Tuxford had refuelled the Vulcan, which

proceeded to its target, arriving at 04.46, dropping its bombs on the runway and creating damage to the air base's hangars.

Fig 54. Vulcan bombing raid air refuelling plan



Five of the coded Black Buck operations were flown by the Victors, of which the last took place on 11 June 1982, a few days prior to the Argentinians surrendering. Each operation lasted for sixteen hours, with the transfer of fuel amounting to 500,000 lb (62,500 imperial gallons, or 218,250 litres) of fuel during eighteen refuelling contacts, all of which were at night. Typically one equivalent operation from RAF Marham in Norfolk would have taken the Vulcan non-stop to China.

By 16 June 1982, numbers of Nimrod and Hercules aircraft had been equipped with refuelling probes. The Nimrod commenced the first of fifteen maritime reconnaissance flights, and the number of Victors deployed varied depending on the distance to the zone of operation. Likewise, the Hercules began dropping supplies to ships of the Task Force that were positioned on the north-eastern edge of the now defined Total Exclusion Zone of the Falklands, preventing any interference by the Argentinian Air Force. Such an operation necessitated one fuel transfer

approximately 1,800 miles south of Ascension. Later, however, this operation required two fuel transfers as the ships of the Task Force neared the Falkland Islands. Owing to the difference in airspeed between the Victor and the Hercules, a new type of rendezvous had to be devised. This was to become known as the 'Overtake Rendezvous', and it depended on the accuracy of the newly installed inertia navigation equipment mentioned previously for its success. Owing to the maximum airspeed of the Hercules being very close to the minimum airspeed of the Victor, the earlier method of 'tobogganing' was initially introduced. To ensure that a contact was made with the technique, the tanker was required to enter a slow descent, with the Hercules following, such transfers commencing at 23,000 feet and being completed at an altitude of between 10,000 and 5,000 feet.

At the same time as the Black Buck operations, Victors were also assisting in ferrying Harrier aircraft from the United Kingdom to the Atlantic Conveyor, which was steaming south to her final resting place. However, Hercules tankers also supported the Harrier at the end of Operation Corporate, as illustrated below, which shows a Harrier on patrol refuelling from a Hercules tanker off the Falkland Islands.

Hercules single-point tanker refuelling a Harrier



The tasks carried out by the Victors brought the tanker fleet sharply into focus for the first time since its inception some twenty-five years earlier. And the public had become aware of its existence through the television news coverage. The operational statistics showed the tanker fleet's contribution to Operation Corporate in the ten weeks of hostilities: Nos 55 and 57 Squadrons flew 3,000 flying hours, completed 600 refuelling sorties, and transferred 12,000,000 lb (1,500,000 imperial gallons, or 6,750,000 litres) of fuel.

Throughout the whole period only two failures occurred with the refuelling equipment when a fuel transfer could not take place, thereby accumulating a failure rate of 1%.

Owing to the Victor K Mk 2 tankers being committed to support aircraft en route and carrying out surveillance of the Falkland Islands, an urgent requirement arose for additional tanker aircraft. It was therefore decided to convert six Lockheed C-130 Hercules C Mk 1 and six Avro Vulcan B Mk 1 aircraft into single-point tankers. The former would provide additional support to the Falkland Islands, and the latter would supplement the Victor tanker force for the defence of the United Kingdom. It is interesting to note that at this time a hunt was being carried out to find further Mk 17B refuelling packages to enable the Hercules and Vulcan aircraft to be converted and have spare packages available. One package was known to be at RAF Marham for ground training purposes, and a further two at RAF Cardington. However, the latter two were found to be Mk 16 packages from the earlier Vickers Valiant single-point tankers, and these were in storage as a part of the Royal Air Force's historical heritage. Even so, it was thought that if necessary they could be modified up to the Mk 17B standard and thus used, but a problem arose in respect of their removal from Cardington, as it was necessary to have the permission of Parliament before such an action could be taken. Nevertheless, sufficient packages were found to be available for the conversions, although whether spares would be

available was another question, and the two Mk 16 packages remained in storage.

During the afternoon of Friday 30 April, Marshalls of Cambridge was requested by the Ministry of Defence to convert six Lockheed C-130 C Mk 1 aircraft into single-point tankers as quickly as possible using the existing Mk 17B refuelling package. On 1 May 1982 the first Hercules XV.296 was delivered to Cambridge for the conversion.

On Monday 3 May I was urgently called to a meeting at Marshalls of Cambridge to discuss the installation requirements of the Mk 17B refuelling package. The necessary design information was flown from Hurn Airport, Bournemouth, to Cambridge by Mr D. Ashover AFC in the company's Baron aircraft. On arrival I was met by Mr R.O. Gates, executive engineering director, and Mr N. Harry, chief designer (both later being recognized for their work by the award of an OBE), to discuss the location of the package, the refuelling hose trailing angles at the various airspeeds and altitudes, and the necessary electrical and fuel requirements to operate it. The meeting visited the aircraft to determine the positioning of the package, drogue stowage tunnel and the control panel. It was concluded that the package would be mounted to the rear cargo ramp, and the drogue stowage tunnel, together with the contact lights, to the upper cargo door; and the control panel would be located at the navigator's position on the flight deck. When we had initially determined the positions of the basic equipment, the systems requirements were discussed, together with the hose trailing angles, thus enabling Marshalls to position the refuelling package at the correct attitude on the cargo ramp. Once all the requirements were agreed, by 5 May 1982 initial orders for the necessary components and materials were being placed, together with the manufacture. The first Hercules tanker conversion, XV.296, was completed on 25 May 1982, and between that date and 4 June 1982 the aircraft was prepared for ground

testing.

Finally the aircraft was cleared for service operational use, as shown below, in which the Hercules tanker is being approached by a Hercules receiver, the amber contact lights being illuminated.



Hercules tanker-receiver approach

It was the Falkland's Operation Corporate and its aftermath that led directly to the conversion of the Lockheed Tristar 500 for the Royal Air Force into a tanker aircraft.

The Falklands War not only underlined the importance of refuelling in flight, but also served to accelerate the rate at which the Victor K Mk 2 tankers of Nos 55 and 57 Squadrons were using up their remaining fatigue hours. Prior to the Falklands it was expected that the Victors would serve well into the 1990s, eventually being replaced by the Vickers VC10 three-point tankers. The short-term solution to the extra demand for tankers that was made by Operation Corporate has previously been described by the conversion of the Lockheed C-130 Hercules and the Avro Vulcan B.2 bomber aircraft. With the Falklands operation at an end, the need to add to the Royal Air Force tanker fleet took on some urgency. During this period there emerged a long-term

unplanned requirement to support the military garrison in the Falkland Islands, until longer airfield runways could be built. This meant that staging refuelled Hercules aircraft through Ascension Island had to be continued. The Air Staff soon came to the conclusion that the Royal Air Force required a multi-role aircraft similar to the American KC-10 Extender. In the latter half of 1982 a large number of jet transport aircraft were available, and it became clear that the conversion of a group of such aircraft was the best solution. Two possibilities occurred: the first was the purchase from British Airways of a fleet of six Tristar 500s; the second was to obtain the McDonnell Douglas DC-10s that had been a part of the Laker Airways fleet.

Final proposals on these two options were made by the Ministry of Defence in mid-October 1982. These were made respectively by Marshalls of Cambridge and the McDonnell Douglas Corporation. Having the backing of Lockheed California Corporation, Marshalls proposed to handle the Tristar conversion at Cambridge, while McDonnell Douglas proposed to make use of British Aerospace and possibly Caledonian Airways within the United Kingdom.

Though it might have been thought that the existence of the McDonnell Douglas KC-10 tanker derivative of the DC-10 would give an edge to the latter, there would have been in fact little relative read across to the commercial version, and the Tristar became the final choice after the Royal Air Force's evaluation of the two proposals. The decision to purchase the six British Airways 500s was announced on 14 December 1982, and Marshalls received the contract during February 1983. From the date of the contract, work proceeded on the first of what would be a multi-phase programme to provide the Royal Air Force, by 1990 at the latest, a nine-aircraft squadron of Tristars having tanker/passenger/ freight capabilities. The increase from six aircraft to nine was brought about by the purchase during 1984 of three further aircraft from Pan American Airways.

Though it was the need to supplement the tanker force in the first instance that set the acquisition of the Tristars, there was something of a change of emphasis since the time of the decision being made. While all the aircraft would have a dual tanker/transport capability, and therefore it seemed likely that No. 216 Squadron would operate in the role in which it had a long-respected tradition—that of transporting personnel around the world. This would leave No. 101 Squadron to assume the responsibility of tanking, as the Victors gradually wound down over the following years.

To carry out the task of converting the Tristar, Marshalls required a large new hangar, capable of housing five aircraft at once. In February of 1983, hours after the necessary planning permission had been granted to build the hangar, work immediately commenced, and on its erection, seven months later, the first aircraft entered it. The bottom left photograph illustrates how five aircraft were housed at one time.



The new hangar belonging to Marshalls of Cambridge

Five Tristars in Marshalls' new hangar



The original plans for the conversion of the Tristars were that they would operate in three separate variants after modification. A further undesignated phase was represented by the operation of unmodified aircraft by the Royal Air Force in 1984 and 1985.

Of the six aircraft purchased from British Airways, the first four were to become K Mk 1 tanker/passenger aircraft, the remaining two as KC Mk 1 tanker/freighter aircraft.



Lockheed Tristar K Mk 1 tanker



Lockheed Tristar K Mk 1 tanker

The programme for these conversions was therefore an enormous task, not only with the tanker conversion, which called for additional fuel tanks in the underfloor cargo compartments, and the installation of the twin Mk XVIIT hose-drum units to be located at the aft end of the rear compartment behind the new fuel tanks. It also needed modification to the aircraft's fuel system to provide a totally integrated fuel system, and the installation of an in-flight-refuelling probe.

The freighter conversion required the incorporation of forward freight doors, a cargo-handling system within the passenger cabin and local reinforcement of the cabin's floor to allow for heavy pallet loads in the centre fuselage, and to provide fixed passenger seating on standard pallets.

The following are the details of each of the nine conversions, including their original build numbers.

BUILD No.	CIVIL REGISTRATION	MARK.	TAIL No.
LCC.193V-1157	British Airways G-BFCA	Tank/Passenger K Mk 1	ZD.948.
LCC.193V-1159	British Airways G-BFCB	Tank/Passenger K Mk 1	ZD.949.
LCC.193V-1164	British Airway G-BFCC	Tank/Freight KC Mk 1	ZD.950.
LCC.193V-1165	British Airways G-BFCD	Tank/Passenger K Mk 1	ZD.951.
LCC.193V-1168	British Airways G-BFCE	Tank/Freight KC Mk 1	ZD.952
LCC.193V-1174	British Airways G-BFCF	Tank/Freight KC Mk 1	ZD.953
LCC.193Y-1186	Pan Am N.508	Stan/Passenger C Mk 2	ZE.704.
LCC.193Y-1188	Pan Am N.509	Stan/Passenger C Mk 2	ZE.704
LCC.193Y-1177	Pan Am N.503	Stan/Passenger C Mk 2A	ZE.706

As this book describes the history of air refuelling, the first basic description has to be of the tanker conversion. However, the importance of the freighter conversion requires some mention, and is described later.

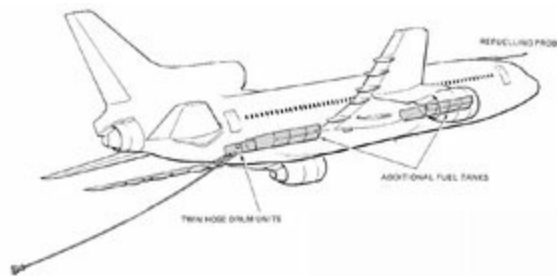


Fig. 55. Tristar tanker, disposition of air refuelling equipment

The tanker conversion illustrated in Fig 55 shows the disposition of the additional underfloor fuel tanks, the twin Mk XVIIT hose-drum units and the refuelling probe.

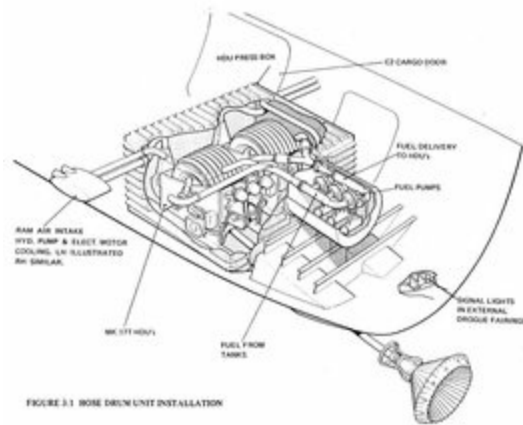


Fig. 56. Tristar tanker twin hose-drum unit installation

The underfloor fuel tanks comprised four fuel cells and a collector tank in the forward cargo compartment, which was designated as a fuselage tank 4F, while the aft tank had three cells and a collector tank designated as 4A.

The twin hose-drum units were located side by side within a pressure box, and access to them was by a large access door on the starboard side of the box structure, which permitted the units to be removed through it, as shown in Fig 56.

The in-flight-refuelling probe was mounted external to the fuselage above the aircraft's flight deck, and offset to the starboard side, in order to clear the emergency exit above the pilot. Besides being offset, it was also angled down some seven degrees from the aircraft's datum. The angle was selected to match the typical nose-up attitude during a refuelling operation when it received fuel, although the aircraft's attitude did vary with aircraft speed and all-up weight.



Tristar receiver probe

Mr B. Chilcott (the then sales manager of the military systems division of Flight Refuelling Ltd) and I visited Marshalls in November 1982 to discuss the proposed installation of the refuelling equipment, and met Mr R. Gates (executive engineering director) and Mr N. Harry (chief designer). From the discussion it was learnt that two hose-drum units were to be mounted side by side within the aircraft's C.3 cargo compartment. The reasoning behind having two units was for redundancy purposes, so that if one unit failed to operate the second could be used, thereby preventing an operation from being aborted. It was also learnt that the Sargent Fletcher Company of California (an American company that produced in-flight-refuelling equipment) was the forerunner to supply the necessary hose-drum units, particularly as the existing Mk 17B was too large to fit in the compartment. The major problem with the unit was its support structure for installation purposes, which also carried the fuel and transfer system. It also came to light that Marshalls had been informed that the support structure could not be divorced from the basic hose-drum unit. I pointed out that the support structure was of historical origin, commencing with the Valiant tanker in the fifties, and was carried on to the Victor K Mk 1 and Victor K Mk 2 conversions, as the equipment was installed within a

large bomb-bay. It was found that the Sargent Fletcher Company were to supply a basic hose-drum unit only, without the fuel-pumping control system, and that Marshalls was going to design the system. Further to these facts, the hose-drum unit would only be required to trail 70 feet of refuelling hose, and not the 80 feet as on the Mk 17B refuelling package, and the speed range was to be between 180 and 320 knots. Knowing this information, I informed the meeting that as a basic hose-drum unit only was required, together with a reduced length of refuelling hose, the basic hose-drum unit of the Mk 17B package could be reduced to a size similar to that of the Sargent Fletcher equipment, and the operation and spares requirement would be the same as the Mk 17B, thereby reducing the overall costs, as they were already in existence. The meeting concluded that if the hose-drum unit could be of a smaller size then the overall concept would be very advantageous.

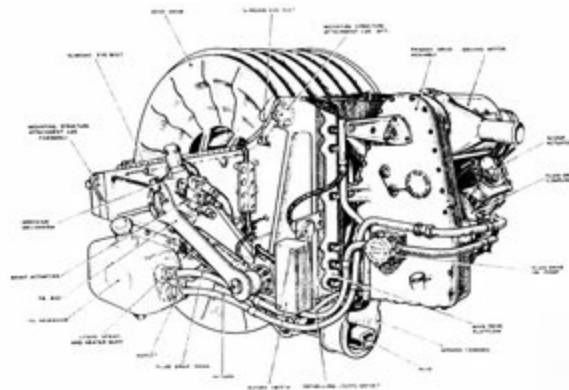


Fig. 57. Mk XVIIT hose-drum unit

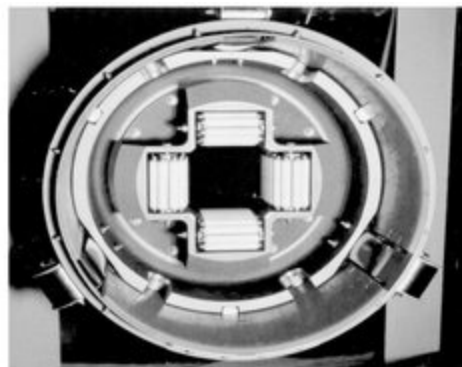
As a result of the meeting at Marshalls, and having discarded the support structure and fuel system of the Mk XVIIB, the necessary reduction in overall size of the hose-drum unit was achieved. The new unit was designated as the Mk XVIIT, as shown in [Fig 57](#).

This, then, would provide the Royal Air Force with a new

unit of proved operational use, with the same spares and maintenance requirements as that of existing equipment employed on the Victor and VC10 tankers.

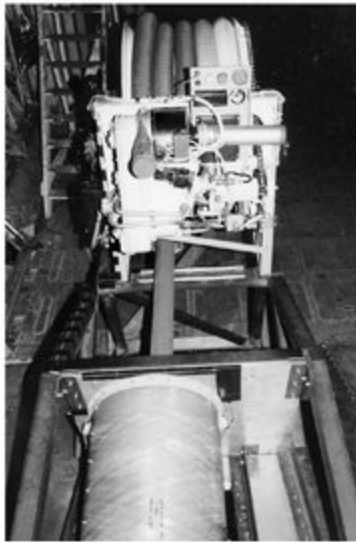
A further meeting with Marshalls confirmed the suitability of the Mk XVIIT for the Tristar, and Flight Refuelling Ltd was then requested to investigate a means of ejecting the reception coupling and drogue from the aircraft, and the possibilities of using one drogue through the speed range of 180–320 knots. Previously on the Victor tanker it had been necessary to use two drogues—one for the speed range 180–230 knots, and the other 230–320 knots. However, the hose-drum system in the Tristar was reverting to a similar fluid drive scoop setting system as used on the earlier Valiant tanker. It was considered worth further investigation to develop the single-drogue philosophy, and for this development it was also considered that the initial flight testing should be carried out using a Hercules aircraft. The installation of a Mk XVIIT hose-drum unit could be similar to that employed for the Falklands conversion, but not incorporating a fuel system, as dry contacts would provide the solution.

To enable the reception coupling and drogue to be ejected, thereby opening the drogue's canopy, Flight Refuelling Ltd designed a drogue ejector tunnel. The tunnel comprised a reinforced glass-fibre tube carrying an internal ejector assembly, and the tunnel was secured to the aircraft's structure aft of the hose-drum unit.



Tristar tanker drogue ejector tunnel

It was agreed to develop experimentally a single operational drogue for the Tristar tanker operation, and that the prototype Mk XVIIT should be installed in a Hercules aircraft for that purpose. The aircraft which had the installation incorporated was Hercules C Mk 1 XV.177. However, the installation of the hose-drum unit and ejector tunnel were located on the port side of the cargo ramp, as shown here.



Mk XVIIT hose-drum unit in Hercules XV.177

To expedite the prototype Mk XVIIT hose-drum unit, it was recommended that a Mk XVIIB unit could be supplied to Flight Refuelling Ltd, from which the components could be used, and by machining the existing hose drum down by one hose layer it would only require new hose-drum-unit side-plates to be manufactured.

Flight trials of XV.177 commenced on 31 October 1983, and were concerned with achieving a satisfactory air refuelling operation through the speed range 180-320 knots IAS through the altitude range. A total of ten flights took

place, totalling thirty hours' duration, during which various drogue sizes were tested, and they finally ended in a successful system achieving the requirements.

In the meantime the Tristar design was continuing with their conversion, and after further discussions with Mr R. Gates and Mr N. Harry it was concluded that the operation and control of the Tristar's system in the tanker role would be similar to that of the Victor and VC10 tankers. Thus some of the components from the fuel-transfer system of these tankers could be incorporated in the Tristar system. Also, some of the components from the existing control panel for the hose-drum unit that was being redesigned to conform with the aircraft's configuration could be used. Flight Refuelling Ltd agreed to assist in the supply of the various components.

The first converted aircraft commenced its clearance certification for service use in July 1985 at A&AEE Boscombe Down, but the first aircraft, K Mk 1 ZD.953, shown taking off from Cambridge, was handed over to the Royal Air Force on 24 March 1986.



Tristar K Mk 1 ZD.953 taking off from Cambridge

Sir Arthur Marshall KT, OBE DL, chairman of Marshalls of Cambridge, is shown below handing the aircraft over to the Controller Aircraft, Air Marshal Sir David Harcourt-Smith KCB, DFC, CBIM, RAF.



Sir Arthur Marshall handing over Tristar K Mk 1 ZD.953

Sir Arthur initially made a speech of welcome to the guests, which included the long association he had had with the late Sir Alan Cobham, the founder of Flight Refuelling Ltd, and Sir Michael Cobham, and I felt that the handover speech should be incorporated in this history.

Sir David, the Tristar tanker Air Staff requirement was a very demanding one and I have a suspicion that you played a major part in setting up some of the coconuts.

I know there is still much to be done and proved in service, but to date, and keeping our fingers crossed, some of those coconuts have been dislodged, including the all-important rate of fuel transfer to a receiver aircraft which, in the case of the Phantom, has exceeded the specification by over 25%, and in the case of the Hercules by over 17%.

I have, in the past, referred to the Hercules as a 'Wily Old Bird', which will be flapping around for many years to come, and I visualize the Tristar tanker fleet will join the Hercules fleet in a long in-service life well into the first half, at least, of the twenty-first century. While not all of us are likely to

be around then, I would like to feel that my company will still be included in whatever is going at the time.

Sir David, it is a great pleasure and honour for me, on behalf of my company, to hand over to you the first Tristar K Mk 1 tanker aircraft Zulu Delta 953.

Air Marshal Sir David Harcourt-Smith accepted the aircraft and then handed it over to the Royal Air Force. Air Marshal Sir Joseph Gilbert accepted the aircraft for the Royal Air Force.

Mr K. Saltrick (managing director of Flight Refuelling Ltd), Mr T. Woodcock (military systems engineering manager) and I were guests at the ceremony.

Mr R. Gates (executive director engineering of Marshalls) is shown in Fig... talking to guests at the handover ceremony.



Mr R. Gates talking to guests at the handover ceremony

During the ceremony of handing over the aircraft, a painting of the first service Tristar refuelling a Hercules over

Cambridge was presented to No. 216 Squadron, which was received by Wing Commander Filbey. The painting is shown below.

In June 1986 Marshalls compiled a proposal for a three-point Tristar tanker by the addition of two Flight Refuelling Ltd Mk 32A refuelling pods, one of each beneath each wing, as shown in [Fig 58](#).

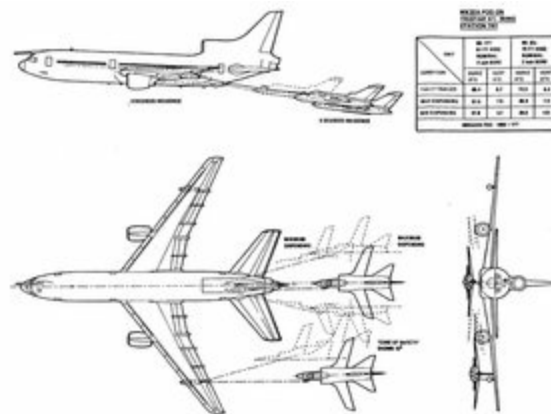


Fig. 58. Tristar three-point tanker proposal

The figure shows the optimum positions of refuelling a Tornado receiver when one of the wing pods had failed, the tanker still being capable of refuelling two aircraft simultaneously.

During the study for the incorporation of wing pods in two wing positions, one inboard at wing Station 741 and the second at 845, a limited simulation of an air-to-air refuelling flight test was carried out using an F-4 Phantom from A&AEE Boscombe Down, and on the basis of this single flight the wing installation appeared to be a feasible option from receiver-handling considerations. However, from the figure the two Tornado aircraft refuelling from the fuselage and wing positions at the same time could come into very close proximity to each other, and this was not addressed in the flight trial. The other aspect was the refuelling hose

length. The existing Mk 32/2800A pod could be fitted at the outboard wing position using the existing 55-foot length of refuelling hose, but at the inboard wing position this length of refuelling hose was unacceptable because of the close proximity to the tanker's tailplane. Therefore it was recommended to increase the hose length to 79 feet, but a hose stability assessment should be carried out before accepting the revised length. It was initially agreed to fly an increased length of the Mk 32 refuelling hose mocked up on an existing VC10 tanker's Mk 17B hose-drum unit, but it was rearranged for a Victor tanker to carry out the test, and this was successfully completed.



Painting of Tristar refuelling Hercules over Cambridge

Nevertheless, after all the trials and the work carried out by Marshalls of Cambridge and Flight Refuelling Ltd, the project was abandoned.

During January 1984 an investigation was requested for the provision of the 'Buddy-Buddy' refuelling capability of the first sixteen IDS United Kingdom Tornado aircraft. The investigation gave an assessment of the availability of the 'Buddy-Buddy' pod options and of the aircraft modifications

that would be required.

At the time there were currently two options available. The first was the Sargent Fletcher 28-300 refuelling store, which was being procured for the German Navy and the Italian Air Force, and the second was the Flight Refuelling Ltd Mk 20B refuelling pod in current use on the Victor and Buccaneer tankers.

It was considered at the time, from the cost and availability point of view, that the Flight Refuelling Ltd Mk 20B was immediately attractive for the following reasons:

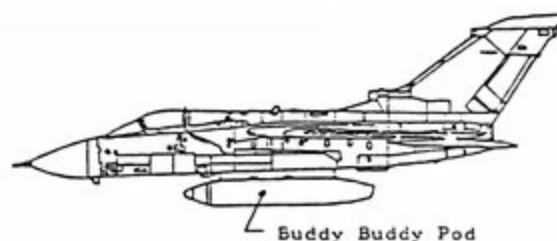
The Royal Air Force already had the technical expertise, and ground test equipment for the Mk 20.

The introduction into service of the VC10 tanker, with the Flight Refuelling Ltd Mk 32/2800 wing pod, and the consequent phasing-out of the Victor tanker (with its Mk 20B wing pods) would mean that the Royal Air Force would have a large number of surplus Mk 20s.

Use of the Mk 20s by the Royal Air Force would maintain the continuity and commonality within the United Kingdom tanker fleet (Buccaneers would still continue to carry Mk 20s).

Although the Mk 20B had a nominally zero purchase cost, it would require a modification to achieve compatibility with the Tornado store carriage system.

The position for the carriage of the refuelling pod on the Tornado was the fuselage position using the MACE attachment, as shown below.

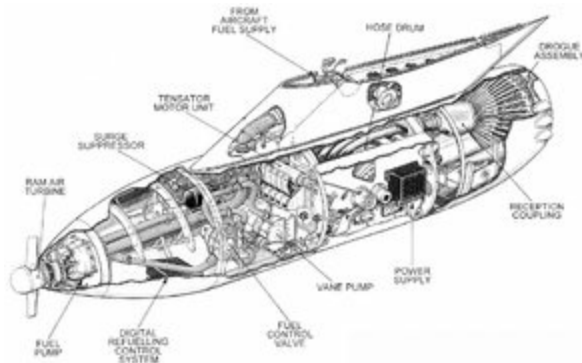


Mk 20G refuelling pod on Tornado tanker

The modification to the Mk 20B refuelling pod necessitated a revision of the pod's interface connections, which included the aircraft attachment, fuel, air and electrical connections, and it was therefore redesignated as the Mk 20G.

Electrical modifications were required to the aircraft regardless of which of the two refuelling pods was to be employed.

The 1980s through to the 1990s became very important to Flight Refuelling Ltd, as the Americans were now interested in fitting the Mk 32 fuel/air system of refuelling pod on their KC-10 Extender and KC-135 tanker aircraft. This was considered a necessity to incorporate a probe and drogue system to refuel their naval aircraft, so that there would no longer be a requirement to fly special missions using the boom drogue adaptor. However, it was not the Mk 32/2800, but the Mk 32B, a variant of the system, that was to be incorporated ([Fig 59](#))



[Fig. 59](#). Mk 32B refuelling pod

The Mk 32B used the same design principle, but repositioned various small assemblies and changed the hose-drum control valve to a rotary type and updated the electronics and had a redesigned control panel. It was

eventually accepted by the American Air Force for the KC-10 and the KC-135R.



USAF KC 10A refuelling USN F-14A Tomcat



USAF KC-135R refuelling USN F-14A Tomcat

The French Air Force was soon to follow, having its KC-135 tanker aircraft converted by having the Mk 32B incorporated, as shown.

The Australian Air Force also became interested in having tanker aircraft, but it had the Boeing 707, which it decided to convert. Israeli Aircraft Industries of Tel Aviv had done previous conversions of this type. The recent Peruvian Boeing tanker conversion had the Mk 32/2800 incorporated, and so the Australians requested them to convert their Boeing 707 aircraft, but using the Mk 32B, the installation

being similar to the former one.

The technique of air refuelling was born during my lifetime, and I was fortunate to have spent virtually forty very interesting and exciting years in the design and development of the equipment.

However, it was through Sir Alan Cobham's dogged determination after years of frustrating trials without the system becoming operational, either commercially or militarily, that in the 1950s the United States of America recognized its advantages. Through his efforts the world's air forces now have what has become through in-flight refuelling a 'Force Multiplier', as has been demonstrated with the recent long-distance aggression.



USAF KC-135R refuelling USN F-14A Tomcat



French Air Force KC-135R refuelling Mirage IV, and Mirage 2000 standing off



Royal Australian Air Force 707 refuelling F-18

Technology

CHAPTER FOUR

Boeing B-29 Superfortress

Three-Point Tanker

The installation of the refuelling equipment included a Mk XI hose-drum unit at each wingtip, and a retractable Mk IX located in the fuselage aft of the rear pressure cabin. Two operators were required to control the equipment, being situated in the rear pressure cabin; the right-hand operator was the master operator, having control of the right-hand wingtip unit, and the fuselage unit, together with the fuel pumps and main electrics of the installation. The left-hand operator, having control of the left-hand wingtip unit only, received instructions from the master operator.

The aircraft was capable of transferring 3,875 imperial gallons (4,650 US gallons, or 17,437 litres) from its rear and forward bomb-bay fuel tanks, being pumped by four centrifugal pumps.

The fuel system is shown in diagrammatic form in [Fig 60](#).

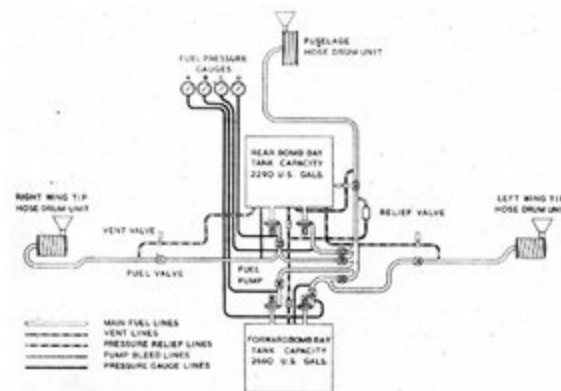


Fig. 60. Boeing B-29 Superfortress three-point tanker-fuel system diagram

As already stated, the storage of the transferable fuel was in the forward and aft bomb-bay fuel tanks, separated from the aircraft's fuel system. They were of the standard type as fitted for the original looped hose tanker configuration. The disposition of the system is shown in [Fig 61](#).

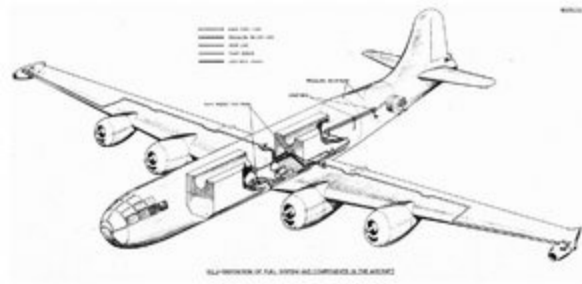


Fig. 61. B-29 Superfortress three-point tanker-disposition of equipment

Four electrically powered centrifugal fuel pumps were employed to transfer the fuel in flight, these being located in the aircraft's scanner bay; two of them were mounted at the forward end of the bay and connected to the forward fuel tank, the other two at the rear of the bay and connected to the rear fuel tank.

The fuel pumps were purpose-designed by Flight Refuelling Ltd, each powered by a Jack and Heinz 27 V DC motor rated at 9.50 horsepower ([Fig 62](#)).

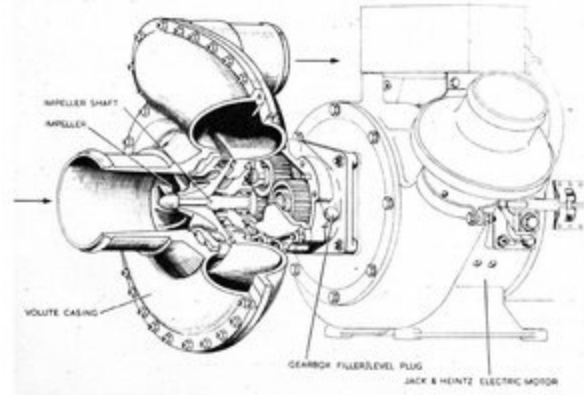


Fig. 62. 9.5 h.p. centrifugal fuel pump

The cooling of the electric motor was by a fan fitted to the drive end of the armature, and air was drawn over the commutator and brush gear through the hollow armature. Two forward-facing scoops protected by ice guards were mounted on the underside of the fuselage, the left scoop via a pipe to the two forward motor/pump units, and the right scoop to the rear motor/pump units, these providing ram-air to assist the cooling. The fuel pumps were Mk 4 Series 2 type, capable of delivering a fuel flow of 212 imperial gallons (255 US gallons, or 954 litres) per minute at approximately 68 psi pressure rise.

To transfer fuel to the rear unit (Mk IX hose drum), the fuel outlets of the four centrifugal fuel pumps were connected to a collector box having a fuel shut-off valve in each connection. The outlet of the collector box faced aft, to which a fuel line was connected running alongside the rear fuel tank, and in which a shut-off and vent valve were incorporated, the fuel line then passing through the rear pressure cabin, having pressure-tight bulkhead connections at its entry and exit at the floor level, thence to the hose drum's rotating fuel joint.

To transfer fuel to the right-hand wingtip unit (Mk XI hose drum), the right-hand fuel pump was mounted to the rear fuel tank and a shut-off valve connected to its outlet. To this

a bifurcated fuel pipe was attached; one of the bifurcations joined the fuel collector box supplying fuel to the rear unit, and the other to a fuel line that ran through the aircraft's right wing to the wingtip unit, also incorporating a fuel shut-off and vent valve, and thence to the unit's rotating fuel joint; the shut-off valve to the rear unit remained closed during a wingtip fuel transfer.

Similarly, to transfer fuel from the left-hand unit (Mk XI hose drum), the fuel pump mounted on the left-hand side of the forward fuel tank had a shut-off valve connected to its outlet. A bifurcated pipe was attached to this, one of the bifurcations joining the fuel collector box, the other running through the aircraft's left wing to that wingtip's unit's rotating fuel joint, which also included a shut-off and vent valve.

The vent valves in the wing's supply line and rear fuselage unit supply line were all connected to the rear bomb-bay fuel tank. This enabled the excess fuel in the refuelling hose, when a contact was made by its contraction, to be returned to a fuel tank.

Incorporated in the fuel line between the forward and rear bomb-bay tanks were two non-return valves, which prevented the flow of fuel between the two tanks. This line was also connected to a pressure-relief valve, which in turn was connected to the rear fuselage hose drum's supply line, being located between the fuel collector box and the fuel and vent valve. The valve was a simple spring-loaded type set so that it began to open at 28 psi, and was fully open at 50 psi. This ensured that during a fuel transfer from the rear fuselage unit (Mk IX), the fuel and vent valve in the supply line could be opened and closed automatically as the receiver changed its position. The sudden closure of this valve during a high fuel flow rate would cause a 'flick' pressure (a momentary surge), the relief valve being opened by this pressure rise, permitting dispersal of the pressure, the excess fuel being returned to the two bomb-bay tanks.

Two fuel pump bleed lines were also incorporated, one being connected to the rear bomb-bay tank from the right-hand wingtip supply line, the other from the forward bomb-bay tank to the outlet of the shut-off valve connected to the left-hand pump.

Each of the four pumps had a connection from its outlet to a pressure gauge, indicating the fuel pressure developed by each pump. They were located in the rear pressure cabin adjacent to the master operator's position.

To ensure that the bomb-bay fuel tanks were never totally drained of fuel, each tank had mounted internally at a low level an FR-type float-switch ([Fig 63](#)), which operated when the fuel level registered only 300 imperial gallons (360 US gallons, or 1,350 litres) remaining. When the float-switch operated, the shut-off valves at the fuel pump's outlets were automatically closed.

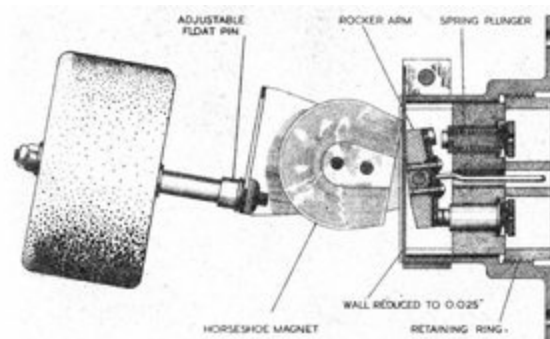


Fig. 63. Low-level float-switch

It always had to be borne in mind that there were two separate refuelling systems in the three-point tanker; one being a high rate of flow from the rear fuselage unit, the other a low rate of flow from the wingtip system.

To enable fuel to be delivered under pressure to the fuselage hose drum, the wingtip hose drum's fuel shut-off valve would have to be closed with the vent open. Also, the

rear fuselage unit's fuel shut-off and vent valve would have to be in the 'Auto' position so that its operation was controlled by the hose drum's rotation. All four fuel pump master switches were selected to 'ON' with the pump speed set to a minimum, which also opened the shut-off valve in the outlets on the collector box, also opening the shut-off valves on the two forward fuel pump outlets and the left-hand pump outlet of the rear bomb-bay tank. Three of the fuel pumps were then manually selected for increased speed.

The pumps were indicated on a fuel system indicator panel (Fig 64) located in the rear pressure cabin at the master operator's position; the panel also indicated whether the valves were OPEN or CLOSED. A second panel identical to that of the master operator's was located at the flight engineer's station on the flight deck; this panel comprised a series of illuminated channels and showed the condition of the fuel tanks, valves and pumps. The appropriate channel and valve positions were illuminated when a particular fuel circuit was in use; typically, when a valve light was ON it indicated that it was OPEN, and when out CLOSED.

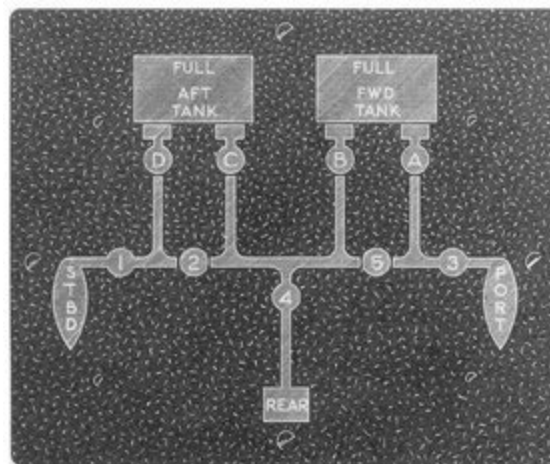


Fig. 64. Master operator's indicator panel

With the pumps and valves in the positions outlined above,

fuel could be transferred to the receiver aircraft from the rear fuselage unit only. While the transfer was taking place the bomb-bay tank that had two of the three pumps off-loading it would obviously empty its contents faster than that of the tank serviced by one pump. The indicator panel would show a drop in the fuel level when the light controlled by the low-level float-switch went out. At this point the master operator would change the order of the pumps in use, so that the tank supplying two pumps now only supplied one; conversely, the tank that was supplying one now supplied two.

When it was required to transfer fuel from the wingtip units, the fuel shut-off and vent valves in their wing supply lines would be switched to AUTO, being under the control of the respective hose drums, and the fuel shut-off and vent valve to the rear fuselage unit supply line to CLOSED. Only two pumps were required in this configuration, the switching of these being similar to that of the rear fuselage unit, except that the pumps used consisted of the one mounted to the right-hand side of the rear bomb-bay tank supplying the right wingtip unit, and the other on the left-hand side of the forward bomb-bay tank supplying the left wingtip unit.

The fuel indicator panel showed the fuel circuit in use and movements in fuel levels of both bomb-bay tanks, but it was not necessary to switch pumps over to maintain a constant level between tanks.

Two Mk XI hose-drum units were incorporated in this conversion—one to each wingtip within specially streamlined nacelles. The two units were identical and therefore interchangeable, both being remotely controlled from the aircraft's rear pressure cabin. The installation other than the fuel system comprised three major components: the wingtip nacelles, the hose-drum unit and its control panel.

The two wingtip nacelles were a light alloy structure supplanting the aircraft's original wingtips, and in this

particular installation were permanent features. The nose of the nacelle had a large ram-air intake, and contained a tripod mounting at its forward end with an attachment to receive an oil cooler. To the rear of this was a protective rain-guard for the hose-drum unit; on the outboard of the left nacelle and the inboard of the right were two air scoops with ice guards. These provided air-blast cooling for the hose-drum unit's motors. The centre section housed the hose drum, which had large hinged doors for maintenance purposes, together with the strong fixing points for the hose drum. The tail fairing of each nacelle had two indicator lights, GREEN and AMBER on its undersurface, so positioned that the lights were visible to the receiver pilot (later these were termed contact lights). A further light was fitted at the extreme end of the fairing to be used for night formatting of the receiver aircraft. An internal light within the nacelle illuminated the hose-drum unit when the unit was in use, this providing further assistance for night refuelling.

The installation of the Mk IX rear fuselage hose-drum unit necessitated structural alterations to the aircraft's rear fuselage, and to accommodate the additional weight of the hose-drum unit and retraction gear. The existing keyhole slot in the underside of the fuselage (between Stations 878 and 968.5), previously used for the fitment of the looped hose system, had structural additions for extra strength and partially to fill the sides of the slot. An additional half former was fitted in the roof of the fuselage at Station 922, two stanchions on each side of the slot connecting the former to the floor. Also in the fuselage roof between Stations 856 and 900, suitably interconnected with existing formers, were longitudinal diaphragms that formed a hinge mounting for two retraction jacks.

A complete bulkhead fitting was fitted across the fuselage at Station 878, on top of which were mounted two hinge castings to pick up the pivot points of the hose-drum unit.

Attached to the left-hand hinge casting was a fabricated arched bracket which held two microswitches interconnected with the hydraulic selector panel containing the controls for raising and lowering the unit, so that the position of the unit could be indicated by warning lights. Positioned between Stations 900 and 917 on each side of the keyhole slot was an up-lock tower containing a solenoid-operated plunger. The 'DOWN' microswitch in the hinge casting was connected through these up-locks so that when the switch was tripped the solenoids were de-energized, allowing the unit to be retracted (see functioning). The two plungers in the up-lock towers were also spring-loaded, and when the unit was fully retracted, these would snap home and positively lock the unit in the 'UP' position. Two cup-shaped blocks were mounted on each side-wall of the keyhole slot to receive the inserts fitted in the ends of the hose-drum unit's cross members when it was in the fully 'LOWERED' position.

Because the keyhole slot in the fuselage floor aft of the hose-drum unit had to be large enough to permit the unit to be 'LOWERED' and 'RETRACTED', a section of the slot would remain uncovered when the unit was retracted. A remotely controlled sliding door was therefore fitted in two runners attached to the upper surface of the fuselage floor. The door was operated by an electrical actuator to which a gear was fitted on its drive shaft to mesh with a length of chain rigidly secured to the underside of the

door. The actuator's limit-switches were removed and replaced by microswitches fitted at each end of the runners, and were interconnected with the circuit for the hydraulic control panel.

To supply hydraulic pressure to the unit's retraction jacks, the existing hydraulic package was used, with some slight modifications. The hydraulic delivery from the package was re-routed and terminated in the new hydraulic panel mounted above the aircraft's fuselage rear entrance door

(Fig 65).

The two outlet pipes from the panel were led directly through a pressure-relief valve to one side of the two hydraulic retraction jacks (operating pressure 350 psi, or 23.8 bar). Selection of either 'UP' or 'DOWN' was via a rotary control valve attached to the panel and operated by a flexible cable connected to the hydraulic selector panel located in the rear pressure cabin at the master operator's position. Special fittings were attached to the rear pressure



Fig. 65. Hydraulic retraction panel

cabin wall so as to enclose the flexible cable, and these prevented the loss of cabin pressure. Attached to the operating lever of the rotary control valve was a cam plate which operated a microswitch wired in series with the rear sliding door.

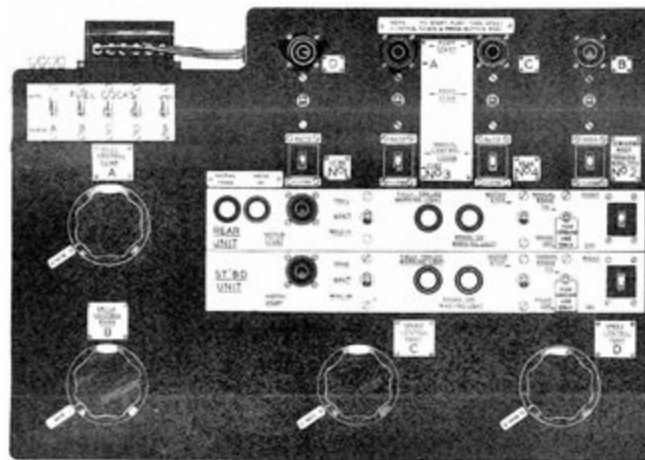
The operating procedure for the hose-drum units is described under the Mk XI and Mk IX paragraphs, and so it is important to describe the overall functional sequence of a refuelling operation with the three-point tanker.

The installation was designed as the world's first three-point tanker aircraft using the probe and drogue system. It was configured to refuel a large aircraft from the rear fuselage unit and two fighter aircraft from the wingtip units.

However, it was also possible to use the rear fuselage unit for fighter refuelling.

When the tanker aircraft had reached the rendezvous and altitude at which the operation was to be made, the fuel-pump stall pressures had to be set prior to trailing any of the refuelling hoses. It was necessary that the four transfer pumps be set at the time so that should reselection of the pumps become necessary during the operation no further action would be required by the operator.

Fig. 66. Master operator's panel



The four main fuel-transfer pump switches on the master operator's panel (Fig 66) were set to ON, all fuel shut-off valves within the system were set to CLOSED, and the four pump switches set to AUTO. The fuel-pump speed control for the pump on the left-hand side of the forward bomb-bay fuel tank was then set to MINIMUM, together with depressing of the pump's START button. The speed control was then set to the correct altitude setting, a pressure gauge indicating the stall pressure achieved would normally be 60 psi (4 bar). It might be necessary to increase the pump's speed control to maintain the pressure but not to exceed it. The first fuel pump having been set, this was followed by setting the

remaining three.

To prepare the wingtip units for a contact, the following procedure was carried out:

1. Ensure that the circuit breakers on the master operator's panel are made, then switch ON the master switches for the two units. When the circuits are 'live' the respective POWER-FAILURE warning lights are illuminated.
2. Switch the fuel indicator panel switch (master operator's panel) to the ON position, the panel being illuminated.
3. Check that the selector switches on the port and starboard operator's panel are in the WIND-IN position.
4. Depress the MOTOR-START button for each unit to start the hose drum's driving motors and allow them to run for approximately five minutes. This ensures that the oil within the fluid drive couplings is warmed to an efficient working temperature. After the warming-up period the current consumption should be 250 amps plus or minus 10.
5. Switch OFF the hose drum's driving motor and wait for at least 15 seconds for the motor to come to rest. Then switch the wingtip fuel and vent valve to the AUTO position.
6. Move selector switch (hose-drum control) to the TRAIL position.
7. Depress MOTOR-START button, and the refuelling hose will start to trail.
8. Control the speed of the trail sequence by use of BRAKE-ON switch.
9. When the hoses are within 6 feet of the fully trailed position the brake on each unit will automatically be applied, which is indicated by the green BRAKE-ON warning light being illuminated.
10. Move the selector switch (hose-drum control) to OPERATION. This action releases the brakes of the units, and the refuelling hose will continue to trail to the

fully trailed position. When the refuelling hoses are at this position the red warning light is illuminated on the respective control panels. It is not necessary to control the speed of the trailing sequence.

11. Switch the required fuel pumps, first the left-hand pump mounted on the forward bomb-bay tank for the port unit, then the right-hand pump on the rear bomb-bay tank for the starboard unit.
12. Both wingtip units are now ready for a contact to be made.

To prepare the rear fuselage unit for a contact the following procedure was carried out:

1. Place the master electrical switch for the unit to ON at the master operator's panel. When the circuit is 'live' its power warning light is illuminated.
2. Check that the hydraulic selector lever is in the UP position on the panel above and to the left of the master operator's panel, and that the circuit breakers are closed.
3. Select NORMAL on the hydraulic panel, which applies power to the hydraulic package, and is indicated by the red warning light being illuminated. As previously described, if the package should fail to start the switch should be moved to ALTERNATE, thus starting the reserve hydraulic pump.
4. Select DOOR-OPEN and ensure that when the door is fully open its green indicator light is illuminated.
5. Select DOWN with the hydraulic selector lever, the unit being lowered to its fullest extent. It is important to ensure that the unit is fully extended, indicated by the UNIT-DOWN light. The hydraulic package can now be switched to OFF.
6. On the rear unit's control panel ensure that the selector switch (hose-drum control) is in the WIND-IN position, depress the unit's START button and hold long enough to ensure that the oil within the fluid drive coupling has

reached its efficient working temperature.

7. When the unit is warmed switch the fuel and vent valves in the unit's fuel line to AUTO and select the required fuel pumps. These are either the two pumps mounted on the rear bomb-bay fuel tank, and the right-hand one on the forward bomb-bay fuel tank, or the two on the forward bomb-bay tank and the left-hand one on the rear bomb-bay tank. In each case the respective shut-off valves within the pump's outlet connected to the collector box have also to be opened.
8. Move the selector switch (hose-drum control) to the TRAIL position.
9. Depress and hold the MOTOR-START button until the INITIAL-TRAIL warning light is extinguished, whereupon the button should be released, the driving motor continuing to run and the refuelling hose to trail.
10. Control the speed of the trailing sequence by the BRAKE-ON switch.
11. The refuelling hose is allowed to trail to the fully trailed position until the FULLY-TRAILED and BRAKE-ON lights are illuminated.
12. Switch the driving motor to OFF and wait for 15 seconds, allowing the motor to come to rest.
13. Move the selector switch (hose-drum control) to OPERATION.
14. The unit is now ready for contact to be made. During contact and refuelling, the operation of all three hose-drum units and fuel system would be completely automatic. As the probe of the receiver made contact with the reception coupling and drogue, the distance between the two aircraft was reduced, the action of the fluid drive coupling taking up any slack refuelling hose, thus maintaining a hose tension. The fuel and vent valves applicable to the unit in use would operate according to the length of refuelling hose trailed, and the AMBER and GREEN contact lights would indicate to the receiver pilot whether the valves were open

or closed. No action was required of the operator during the refuelling.

At the conclusion of the fuel transfer, and after the receiver had broken away from the unit with which it had been in contact, the refuelling hose now at the fully trailed position, the procedure for recovering it was as follows:

1. Switch off the fuel pump or pumps that have been in use.
2. Switch OFF the hose-drum unit's driving motor, and allow 15 seconds to elapse so that the motor comes to rest.
3. Move the selector switch (hose-drum control) to the WIND-IN position.
4. The refuelling hose will commence to wind in, and will continue to do so until the reception coupling enters the serving gear guide. This is indicated by the BRAKE-ON warning light being illuminated.
5. Switch OFF the unit's driving motor and the brake will automatically be applied.
6. Switch the used wingtip fuel and vent valves to CLOSED.
7. Switch OFF the master switches for both the unit and fuel pumps.

The procedure for the rear fuselage unit was as follows:

1. Switch OFF the fuel pumps that have been in use.
2. Switch OFF the unit's driving motor and allow 15 seconds for it to come to rest.
3. Move the selector switch (hose-drum control) to the WIND position.
4. The refuelling hose will then commence to wind in. However, the operator has to check that the unit's driving motor is automatically switched OFF when approximately 6 feet of refuelling hose remains trailed; this is due to the inertia of the hose drum continuing to wind.
5. After 15 seconds' pause, depress the MOTOR-START button and hold until the reception coupling is in the

fully stowed position, indicated by the HOSE-IN green light being illuminated.

6. Switch the fuel and vent valve in the fuel supply line to the CLOSED position.
7. Select NORMAL on the hydraulic package control panel, the package being started and the red warning light illuminated.
8. Select UP with the hydraulic selector lever; the unit will then be retracted into the fuselage. It is important that the unit is fully retracted and confirmed by the UNIT-UP indicator light.
9. Select DOOR-CLOSE and confirm its closure by the indicator light.
10. Switch OFF the hydraulic package.
11. Switch OFF the master switches.

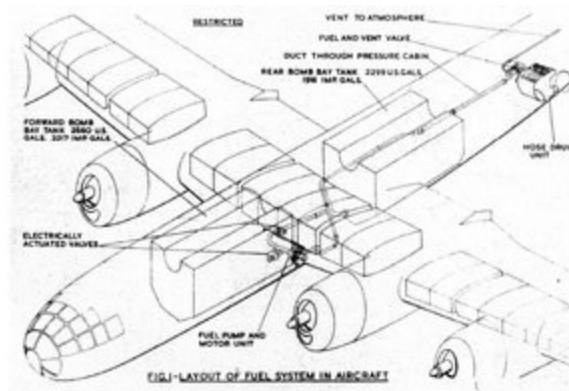
CHAPTER FIVE

Boeing B-29 Superfortress

Single-Point Tanker

The Boeing B-29 Superfortress single-point tanker had the capability to transfer 4,135 imperial (4,962 US) gallons of fuel at a fuel flow rate of 208 imperial (250 US) gallons per minute.

The main components of the system are shown diagrammatically in [Fig 67](#).



[Fig. 67](#). Boeing B-29 Superfortress single-point tanker

These were:

1. A centrifugal fuel pump electrically powered.
2. Hose-drum unit MkVII Series I.
3. Reception coupling and drogue.
4. Electrically operated fuel shut-off valves.

The fuel was supplied to the hose-drum unit from the

forward and rear bomb-bay fuel tanks, the capacities of which were 3,220 imperial (3,864 US) gallons and 1,915 imperial (2,299 US) gallons respectively.

The fuel was fed by gravity from the rear tank outlet located on its forward face, through a 5.00-inch-diameter fuel pipe tapering to 3.00-inches diameter where connected to a Vickers 3-inch shut-off valve. Similarly fuel was fed from the forward bomb-bay fuel tank to the pump via a second Vickers

shut-off valve, the outlet of which joined the main fuel pipe described in the previous paragraph before being increased to 4-inches diameter where it joined the centrifugal pump. The pump outlet was 3-inch diameter pipe, led back along the right-hand side of the rear fuselage to a point on the forward pressure bulkhead of the rear pressure cabin. Here it was connected to a length of flexible hose, which passed through the cabin to the rear pressure bulkhead. The flexible hose was installed within a metal duct secured to the cabin floor, forming a pressure-tight seal where it was connected to the two bulkheads, and also providing protection to the hose from being damaged.

The two Vickers 3-inch shut-off valves were electrically actuated and could be operated either by being switched manually from the flight engineer's panel or automatically by two float-switches, one of which was installed in each fuel tank. These switches ensured that when the quantity of fuel in each fuel tank dropped to approximately 125 imperial (150 US) gallons, the two valves would automatically be closed; irrespective of whether the switches on the flight engineer's panel were ON or OFF.

The centrifugal fuel pump ([Fig 68](#)) was similar to that used in the three-point tanker, a Mk 4 Series 2 type, purpose designed by Flight Refuelling Ltd, but having a different electric motor.

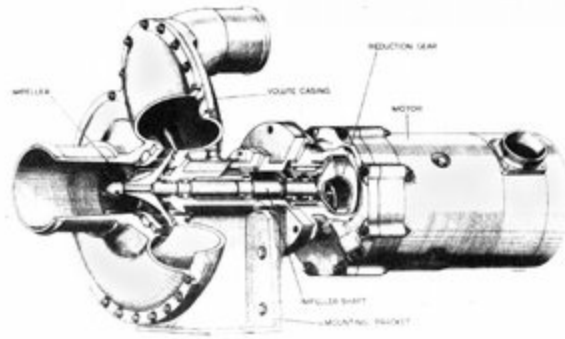


Fig. 68. Single-point tanker fuel pump

The motor on this particular pump was rated at 6.5 h.p. at 7,000 rpm, and was a 24 V DC shunt wound type. A variable resistance was incorporated in the field circuit to enable the motor speed, and therefore the pump's impeller speed, to be increased with altitude. The motor was air-blast cooled in a similar manner to that employed on the three-point tanker. Due to the motor being unsuppressed for radio interference, two suppressors were installed on the forward former of the bomb-bay fairing close to the pump assembly, using double cable connected in parallel. They were connected to the motor by bus-bars fitted within a screened box mounted over the motor terminals.

The pump also had a fuel pipe bleed line connected at its outlet, which went to the forward bomb-bay tank, thus ensuring that when the pump was run in the stalled condition it was protected against overheating.

The main electrical panel for the Mk VII Series I. hose-drum unit ([Fig 69](#)) was installed on the left-hand side of the aircraft's fuselage aft of the hose-drum unit, and contained the master switches for the centrifugal fuel pump and the hose-drum unit. Each master switch comprised three switches ganged together, the hose-drum unit being on the right and that for the pump on the left. Two power-failure warning lights were incorporated above the master switches, being actuated in the event of a power failure caused by the

operation of the circuit breakers. A small electrical panel, also shown in [Fig 69](#), was situated on the left-hand side of the electrical panel but secured to the fuselage floor. This contained an ammeter and a variable resistance for controlling the speed of the centrifugal fuel pump at altitude.

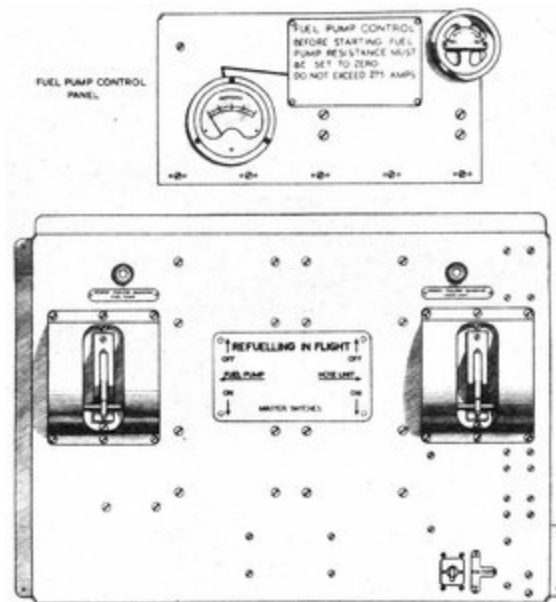


Fig. 69. Main electrical panel

The master switches on the main electrical control panel had to be switched ON prior to either the fuel pump or hose-drum unit being operated. But if during an operation the warning lights were illuminated, it was only necessary to switch the independent one OFF, and restart the respective units. If the warning lights were again illuminated, it was assumed that the power failure was not due to a temporary surge but to a fault within the aircraft's electrical system.

The hydraulic power required to retract and lower the Mk VII Series I hose-drum unit was derived from an existing hydraulic power package on the aircraft.

The hydraulic control panel ([Fig 70](#)) and hydraulic system provided the control for the hose-drum unit in either the

retracted or lowered position, the panel being located on the right-hand side of the aircraft's fuselage and aft of the hose-drum unit.

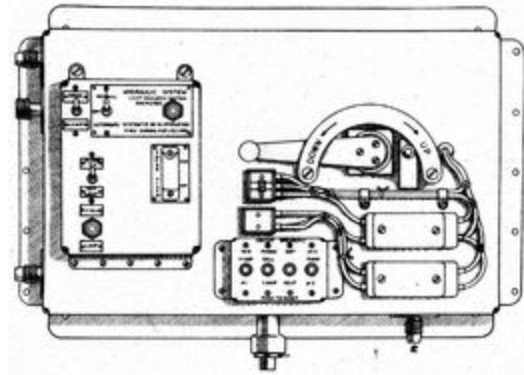


Fig. 70. Hydraulic control panel

The existing hydraulic power supply package was located on the left-hand side of the fuselage aft of the rear pressure cabin door. This unit was similar to that employed on the three-point tanker for the Mk IX hose-drum unit.

The pressure and return pipe lines were led to the panel, the pressure being connected to a pressure-reducing valve; thence it was bifurcated, providing two connections to a rotary control valve; the return line led directly to the valve after being bifurcated, thus providing two connections. The pressure and return lines were then connected to the hydraulic ram mounted above the hose-drum unit, one pair of lines providing the supply for retracting purposes, the pressure line of which was connected below the ram's internal piston; the return was above it. Similarly for lowering the pressure line above the ram's piston and return beneath, the end of the hydraulic ram being mounted in the aircraft's roof at Station 878. The ram's travel was 18 inches, the operating pressure of which was 300 psi (20 bar). Attached to each side plate was a radiused runner, which operated in a guide mounted to each side of the fuselage

cutaway in the floor. The two guides were spring-loaded, and when the unit was fully retracted they snapped home, positively locking the unit in the UP position. The guides incorporated a solenoid, which, when energized, withdrew the catches and allowed the unit to be lowered. Two trunnions mounted on the side plates engaged with two rubber buffer cups fitted on each side of the fuselage cutaway, each incorporating a microswitch, which, when operated, de-energized the up-locks.

The electrical control box attached to the panel provided the master switch for energizing the hydraulic pump unit, and a RED indicator light would be illuminated when the system was energized. Again, its operation was similar to that employed on the Mk IX hose-drum unit's retraction system. Initially the switch would be set to NORMAL, which energized one of the hydraulic pumps and illuminated the indicator light. However, if the pump failed to come on line, the switch was then set to ALTERNATE, thus energizing the second pump.

Adjacent to the master switch was an internal fuselage light switch providing lighting for the operator, which illuminated a domed light in the fuselage roof. Below this switch were the aircraft's intercom switches and call light, enabling the operator to be in contact with the tanker's captain. To the right of the intercom was an emergency switch to enable the operator to warn the captain of any emergencies that occurred during a refuelling operation.

To the right of the above control switches was the operator's selector lever for raising and lowering the hose-drum unit. The lever was secured to the rotary hydraulic control valve, and enclosed within a gated quadrant to ensure positive movement, also locking the lever in either the UP or DOWN positions. Attached to the panel and within the quadrant was a microswitch, which, when the selector lever was moved to the DOWN position, tripped the switch, thereby energizing the hose-drum unit's up-locks.

Below the selector quadrant was a circuit-breaker box containing breakers for each hydraulic pump, the intercom and heating for the rear fuselage.

As the cutaway in the fuselage aft of the hose-drum unit had to be large enough to permit the unit to be lowered and retracted, a portion of the fuselage floor would remain uncovered. Therefore a sliding door was fitted to the fuselage floor and provided a seat for the operator. The door was padded on its upper surface, and slid on bearings that were located in two runners attached to the fuselage floor. A locking mechanism was also fitted, and operated by a centrally placed lever; the lever being connected by rods to two plungers, which protruded on either side, and when in the locked position engaged with bushes mounted on the outside of the door's runners. Two bushes were mounted on each runner, one in the door's closed position, the other in the door's fully opened position. The two bushes fitted to the right-hand runner incorporated microswitches supported in brackets secured to the fuselage floor. The forward microswitch had an indicator light coloured RED fitted adjacent to it, and was so connected electrically that immediately the door locks were withdrawn the indicator light was illuminated, whereby the hose-drum unit operator was warned that the door was unlocked. The microswitch fitted to the rear bush was connected electrically to the switch box on the hydraulic panel in such a manner that, unless the door was locked in the fully opened position, the circuit to the hose-drum unit up-lock was broken and the hose-drum unit could not be lowered.

The electrical system to operate the MkVII Series I hose-drum unit installation is shown in [Figs 71](#) and [72](#), firstly the interconnection of the hose-drum unit, and secondly the hose-drum door retraction electrics. It is not necessary to describe in detail the complete electrical system, as the operation of the equipment is described as an aircraft operational sequence of events.

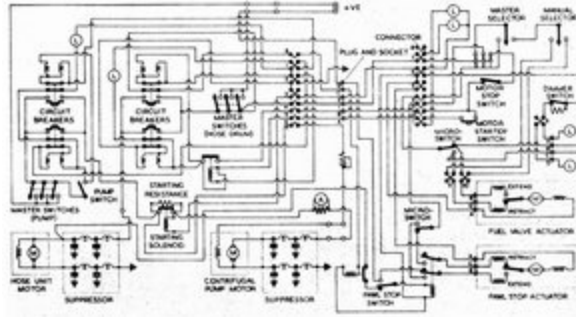


Fig. 71. Mk VII Series I hose-drum unit electrics

The following description is how the complete refuelling operation was carried out with this installation.

Immediately prior to a refuelling operation, the captain of the tanker aircraft informed the refuelling operator, who then took up his position alongside the hose-drum unit. At the same time the aircraft's flight engineer switched the two shut-off valves fitted to each bomb-bay fuel tank to OPEN. The refuelling operator then had to carry out the following procedure:

1. Unlock the sliding door, and move it to the fully OPEN position. It is important that the door is locked in this position, and that the microswitch on the hydraulic panel is tripped.
2. Select the toggle-switch on the hydraulic panel to NORMAL setting, and ensure the RED indicator light is illuminated, thus confirming that the hydraulic pump is operating correctly.
3. Select DOWN with the hydraulic retraction lever, which besides operating the hydraulic control valve operates a microswitch to energize the up-lock solenoids and withdraw them from engagement, permitting the hose-drum unit to be lowered. It is important that the selector lever remains in the DOWN position.
4. Move the sliding door to the fully CLOSED position, and ensure that it is locked, the RED warning light being extinguished.

5. Set the main switches on the main electrical panel, namely the hose-drum unit and fuel pump. With these set to ON, ensure the RED warning light on the operator's control panel is illuminated.
6. Depress the driving motor's START button, ensuring that the GREEN indicator light is illuminated, confirming that the driving motor is running.
7. Select maximum scoop on the fluid drive selector quadrant, release the the brake via the brake lever, then reduce the scoop setting until the refuelling hose commenced to trail. If it is found necessary to control the speed of the hose trailing sequence, apply the hose-drum brake to provide a smooth operation (it is important that the hose is not allowed to trail too fast, as damage could be caused to the pawl stop mechanism).
8. The refuelling hose is allowed to continue trailing until the pawl stop mechanism has been actuated and it is ensured that the fuel and vent valves have operated with the switch set to AUTO.
9. The scoop setting is then increased to approximately 30%, and the hose-drum brake is set to OFF (the degree of scoop setting varies with the aircraft's airspeed at the time of the operation).
10. Switch ON the centrifugal fuel pump (it is important that the variable resistance control is wound out to its fullest extent before this). The control can be wound in at altitude to increase the fuel pump's motor speed, but under no circumstances should the current exceed 275 amps.

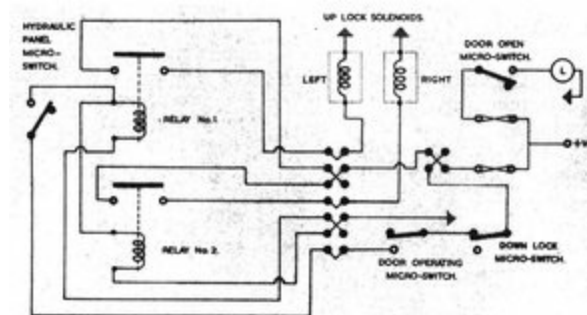


Fig. 72. Hose-drum door retraction electrics

The system was now ready for the receiver aircraft to make a contact. The operator then informed the aircraft's captain that the equipment was ready for a fuel transfer.

During the refuelling operation the system operated automatically, the receiver aircraft moving forwards and backwards, controlling the operation of the fuel and vent valves, the fluid drive coupling taking up any slack in the refuelling hose.

After the refuelling operation had been completed, and the receiver aircraft had broken contact, the refuelling hose was at its maximum trailed length, with the pawl stops engaged and the fuel valve CLOSED and the vent OPEN.

The following procedure was then carried out to recover the refuelling hose, and retract the hose-drum unit.

1. Switch OFF the centrifugal fuel pump.
2. Increase the fluid drive coupling's scoop to the maximum, having informed the aircraft's captain that the receiver aircraft has broken contact. The tanker aircraft's speed is then reduced to a point where the wind-in load of the fluid drive exceeds that of the drogue's drag. It is also possible that it is necessary to control the wind-in the refuelling hose by applying the hose-drum brake.
3. With the refuelling hose fully stowed, the hose-drum brake is applied.
4. Move the sliding door to the fully OPEN position, ensuring that it is locked.
5. Select UP with the hydraulic lever on the hydraulic control panel. The hose-drum unit retracts into the fuselage.
6. Move the sliding door to the FULLY CLOSED position, and again ensure that it is locked.
7. Switch OFF the hose-drum driving motor.

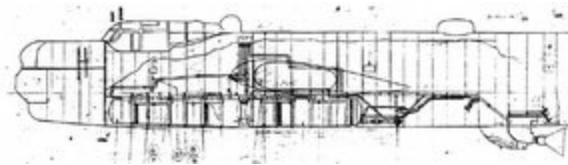
8. Switch OFF the main electrical panel.
9. Finally inform the aircraft's captain that the operation is completed.

CHAPTER SIX

Avro Lincoln Mk II

Tanker RA.657

The conversion of the Lincoln tanker ([Fig 73](#)) utilized the aircraft's bomb-bay for the installation of two 600-imperial-gallon (2,700 litres) cargo fuel-tanks and the fuel transfer system, together with tapping into No. 1 port inner wing fuel-tank containing a further 585 imperial gallons (2,633 litres) of fuel, thereby providing 1,785 imperial gallons (8,033 litres) of transferable fuel at a flow rate of 200 imperial gallons per minute.



[Fig. 73](#). *Avro Lincoln Mk II tanker RA.657*

The fuel transfer system ([Fig 74](#)) supplied fuel to the hose-drum unit located in the rear fuselage radar scanner bay from the two cargo tanks and the port No. 1 inner wing tank, the latter being divorced from the aircraft's main fuel system. The two cargo tanks were designed specifically for in-flight refuelling, originally being employed with the looped hose system in the earlier Lancaster tankers.

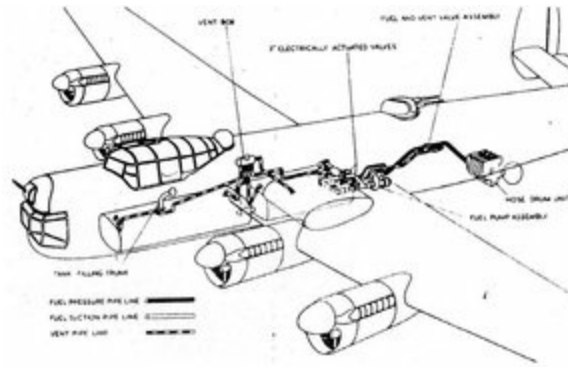


Fig. 74. Avro Lincoln Mk II tanker fuel system

They were both connected by a 6-inch-diameter balance pipe, the outlet of the two tanks being taken from the rear tank by a 4-inch-diameter pipe. This pipe was tapered down to 3 inches diameter and connected to a 3-inch Vickers electrically actuated fuel shut-off valve. The outlet from the valve was another tapered pipe increasing its diameter back up to 4 inches, this being joined to the inlet of a centrifugal fuel pump located between aircraft Stations 16 and 17 within the bomb-bay.

The outlet from the port No.1 inner wing tank was of 3-inch-diameter piping, and led to a second 3-inch Vickers electrically actuated fuel shut-off valve, the outlet of which was fed into the cargo tanks fuel supply pipe adjacent to the fuel pump's inlet.

The centrifugal fuel pump was hydraulically driven from the aircraft's main hydraulic system, and was supplied with fuel by gravity from all the fuel tanks. The fuel pipe from its outlet of 3 inches diameter was tapered down to 2 inches where it was connected to a Saunders electrically actuated combined fuel and vent valve. The outlet from this valve was then connected to the rotating seal gland on the hose-drum unit. A tapping in the fuel pipe on the outlet of the centrifugal pump was connected by a ½-inch diameter pipe to the upper surface of the rear cargo tank, thus preventing overheating of the pump occurring when it was running in a

stalled condition, and thereby preventing overheating and avoiding the consequent danger of fuel vaporization.

Each cargo tank had two vent tappings in its upper surface, these being connected by a 1-inch pipe to a common vent box located above the wireless operator's position in the cockpit. The outlet from the vent box protruded through the port side of the fuselage facing forward. The port No. 1 inner wing tank also had a 2-inch vent pipe fitted, in addition to the existing aircraft vent, and was connected to the common vent box.

The cargo tanks had a common filler neck extension of 3 inches diameter, which was led to the port side of the fuselage, the port No. 1 inner wing tank being refuelled by the aircraft's normal method.

The two electrically actuated Vickers valves were operated by manual switching by a single switch on the 'Refuelling in Flight' electrical panel. They were so wired that when one was open the other was automatically closed, which prevented the head of fuel in the port No. 1 inner wing tank forcing fuel back into the cargo tanks.

The Saunders combined fuel and vent valve comprised a 2-inch fuel shut-off valve and a 1-inch vent valve. The two valves were operated by a common actuator that was electrically controlled via a microswitch on the hose-drum unit. A manual override was on the electrical panel for use in an emergency. The valves were connected to the actuator in such a manner that when the shut-off valve was closed the vent was open, and vice versa. This ensured that after a refuelling operation the fuel that was normally trapped in the refuelling hose was vented back to the rear cargo tank. This also prevented damage occurring to the hose from excessive internal pressures created by the changes in altitude and temperature.

The Mk 4 Series 2 centrifugal pump ([Fig 75](#)) was the same as that used on the Boeing B-29 Superfortress single-point

and three-point tankers. However, in this installation it was driven by an IHC hydraulic motor at a lower rpm, thereby providing a fuel flow rate of 200 imperial gallons (900 litres) per minute at 4,400 rpm, and having a stall pressure of 50 psi.

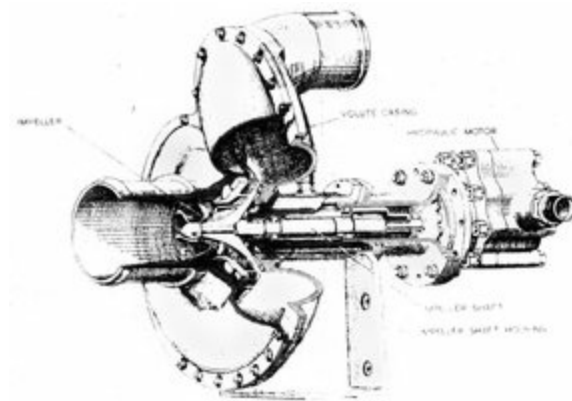


Fig. 75. Avro Lincoln Mk II tanker fuel pump

The hydraulic motor was an IHC Mk 2A hydraulic pump converted into a motor. The conversion necessitated modifications to the pump's casing to decrease the pressure loss through the motor when running at a high speed. The normal operating pressure was between 450 and 600 psi, and a relief valve was incorporated across the inlet and outlet pipes to relieve at 850 psi. The drive from the motor to the pump was transmitted through a coupling that was housed in a flanged adaptor. One end of the adaptor was bolted to the face of the motor, the other to the rear face of the pump's impeller shaft housing.

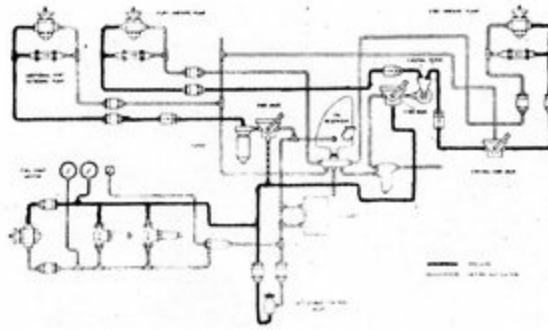


Fig. 76. Avro Lincoln Mk II modified hydraulic system

The power for driving the hydraulic motor was taken from the aircraft's hydraulic system, which was considerably modified to ensure that an adequate volume of hydraulic fluid was supplied to the motor. The modified system is shown diagrammatically in Fig 76.

For the operation of the normal hydraulic components in the aircraft, two hydraulic pumps were fitted, one on the port inboard engine and one on the starboard inner engine. Under normal conditions only the port pump was used; but should this fail, the starboard pump could be brought into the system. The port inboard pump drew fluid from the hydraulic reservoir and delivered it under pressure via a non-return valve, through a filter to the cut-out valve, where it was either led to the general aircraft services or back to the reservoir. At the same time, the starboard inboard pump delivered fluid under pressure, through a three-way valve to the reservoir. If the port pump failed, the three-way cock, located on the front of the wing spar, was moved to 'starboard pump delivery' position, the starboard pump then delivering fluid under pressure to the aircraft's system.

Because the hydraulic motor fitted to the centrifugal fuel pump required a greater volume of hydraulic fluid than could be supplied by one hydraulic pump, both port and starboard inboard pumps were operated together when the fuel pump was required. An additional pump was necessary

to boost the hydraulic supply, and was fitted to the port outboard engine. The new pump drew its supply from the aircraft's general services common return line, and delivered fluid under pressure via a three-way non-return valve, through an additional filter to a new three-way valve located on the rear face of the front wing-spar. The pressure line from this valve was led either back to the hydraulic reservoir, or to the inlet side of the centrifugal fuel pump's motor. A pressure bleed was teed into the motor's inlet, and was taken through an adjustable valve back to the reservoir. The adjustable valve could thus control the amount of hydraulic fluid passing through the motor, thereby controlling its speed, and therefore the volume of fluid delivered by the fuel pump was also varied.

A further three-way valve, located alongside the valve mentioned in the previous paragraph, was fitted to the output side of the existing filter, and when placed in the 'refuelling-in-flight' position, allowed the hydraulic pressure to be fed from the existing pump to the inlet of the fuel pump's motor.

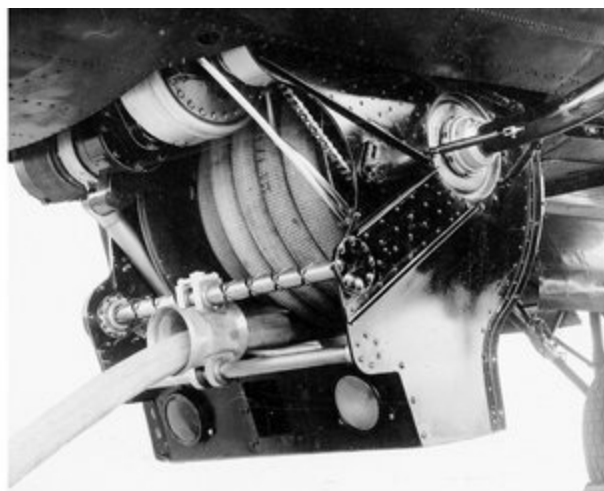
When the system was required for flight refuelling, the emergency three-way valve had to be selected to the 'starboard pump delivery' position. When in this position, it fed hydraulic pressure from both port and starboard hydraulic pumps to the inlet side of the new three-way valve fitted to the output side of the existing filter. This valve also had to be in the 'refuelling-in-flight' position to ensure the pressure from the two existing hydraulic pumps was fed to the inlet side of the fuel pump's motor. The third three-way valve had also to be in the 'refuelling-in-flight' position as it supplied fluid pressure from the new hydraulic pump.

A Dowty pressure-relief valve was also connected across the inlet and outlet pipes of each hydraulic pump as an additional protection, and two Dowty tee-type relief valves were connected across the inlet and outlet pipes of the fuel pump's motor. These tee-type valves were duplicated

because of the high rate of fluid flow through the motor.

The drum unit installed in the Lincoln was a derivative of the Mk VII Series I unit used in the Boeing B-29 Superfortress single-point tanker, and was a non-retractable unit designated as the Mk VII Series II. It was located in the rear fuselage where the H2S radar scanner had been situated, both the radar unit and fairing blister having been removed for the hose-drum unit installation. Its operation and performance was identical to the Mk VII Series I, having the same components and described in the B-29 Superfortress single-point tanker. The installation in the Lincoln being non-retractable, the unit protruded below the underside of the fuselage, which necessitated a large fairing being incorporated at its forward end. It included two ram air cooling ducts, one of which provided the cooling air to the unit's oil cooler, the other to the driving motor.

A dummy floor was fitted over the H2S radar scanner's aperture, which was also squared and reinforced. The hose-drum unit was suspended from the new structure, permitting it to protrude beneath the fuselage, providing sufficient clearance for the reception coupling and drogue when being trailed or wound in.

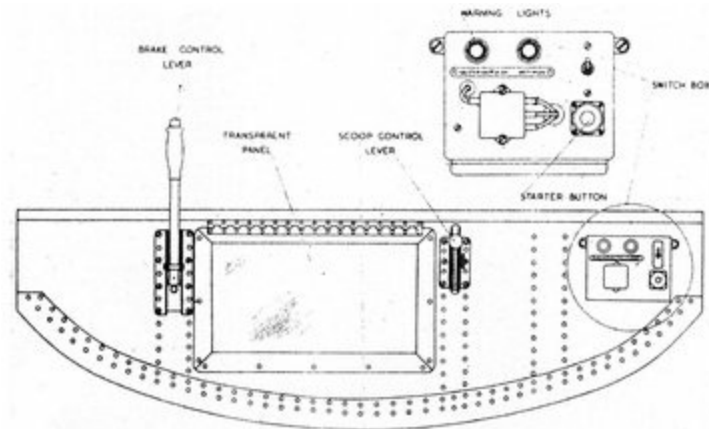


Avro Lincoln Mk II tanker hose drum installation

This was a prototype installation, and the structural alterations were kept to a minimum, thus allowing the aircraft to be returned to its original condition after the trials and demonstrations were completed.

The operator's control panel ([Fig 77](#)) was located in the aircraft's rear fuselage, and was mounted at an angle of 60 degrees between the aft end of the dummy floor and the fuselage's floor, i.e. above and to the rear of the hose-drum unit.

Fig. 77. Avro Lincoln Mk II operator's control panel



On the left-hand side of the panel was the brake control lever, which was connected by a flexible cable to the hose-drum brake. The control lever incorporated a ratchet mechanism that was operated by a push-button on top of the lever. The button had to be depressed to release the brake. A rectangular transparent panel was fitted centrally, so enabling the operator to view the hose-drum unit, and particularly the refuelling hose.

The fluid coupling scoop control lever was located to the right of the transparent panel, being mounted in a quadrant graduated in degrees. The control lever was fitted with a screw locking device so that it could be locked in any desired position.

An electrical switch box was fitted to the right of the fluid coupling control lever, as shown in [Fig 78](#), and housed a press button for starting the hose-drum motor, and a toggle-switch for selecting motor OFF. Two warning lights were fitted—a red that indicated that the panel was electrically live, and a green indicating that the hose-drum-unit motor was running.

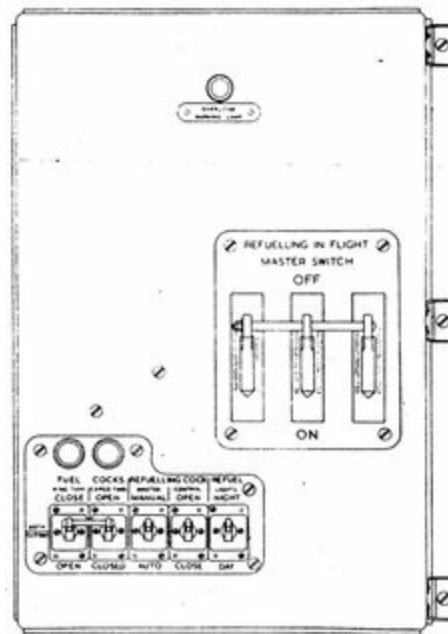


Fig. 78. Avro Lincoln Mk II electrical panel

An electrical panel ([Fig 78](#)) was installed on the port side of the rear fuselage and above the hose-drum unit, which comprised the 'refuelling-in-flight' master switch, and the switches that controlled the position of the 3-inch Vickers valves fitted to the outlet of the port No. 1 inner wing tank and the cargo tanks. It also included the manual and automatic switches for the combined fuel and vent valve, and a dimmer-switch for the hose-drum unit's contact lights.

The master switch comprised three toggle-switches ganged together that had to be selected to 'ON' prior to a refuelling operation. The switches for the 3-inch Vickers

operator, and have been taken from the original operating instructions. Immediately prior to a flight refuelling operation, the captain of the tanker aircraft informed the refuelling operator, who then took up his station alongside the hose-drum unit. The operator then switched the main switches on the 'refuelling-in-flight' electrical panel. He also had to ensure that the adjustable hydraulic control valve in the fuel pump motor circuit was in the fully OPENED position.

The operator must then go forward to the main spar and turn the three-way valves to the 'refuelling-in-flight' position, and select 'STARBOARD PUMP TO DELIVERY'. He must then return to the hose-drum unit and carry out the following instructions:

1. Depress the push-button on the operator's control panel. The GREEN light being illuminated indicates that the electric motor is running.
2. Select maximum scoop on the fluid coupling drive control, release the brake, and then reduce the scoop setting until the refuelling hose commences to wind out. If necessary the speed of unwinding may be controlled by the brake. NOTE It is important that the refuelling hose must not be allowed to run too fast as damage may be caused to the pawl stop mechanism.
3. Continue unwinding the refuelling hose until the pawl stop mechanism has actuated and check that the fuel and vent valve master switch is in the 'AUTO' position.
4. Increase the scoop setting to the correct stall position and ensure that brake is OFF.
5. Select 'Cargo Tanks Open' on the selector switch situated on the electrical panel. NOTE It is important to transfer from the cargo tanks before No. 1 port wing tank.
6. Change the fuel and vent valve master switch to 'MANUAL' and place the control switch in the 'OPEN' position. Screw down the adjustable hydraulic control

valve until the fuel pressure gauge shows 50 psi. Place the control switch to the 'CLOSED' position and return the master switch to 'AUTO'.

The system was then ready for a receiver aircraft to make contact. The operator must inform the captain that the equipment was ready for a fuel transfer.

During contact and while fuel was being transferred, the operation of the system was automatic.

After the flight refuelling operation had been completed, and the receiver had broken away, the refuelling hose would be trailed at its maximum length with the pawl stops engaged and the fuel valve closed.

The operator must then carry out the following procedures:

1. Unscrew the adjustable hydraulic control valve to the fully open position.
2. Increase the scoop setting to its maximum and inform the captain that the receiver aircraft has broken contact. The captain will then reduce his aircraft's speed to a point where the wind-in load of the fluid coupling drive exceeds the drag on the refuelling hose. It may be necessary to check the speed of the refuelling hose wind-in speed by use of the brake.
3. When the refuelling hose is fully wound in, apply the brake.
4. Switch off the tank selector switch.
5. Switch off the motor by operating the toggle-switch on the operator's panel.
6. Switch off the 'refuelling-in flight' master switch on the electrical panel.
7. Go forward and return the three-way valves on the rear spar to 'General Services', and return the valve on the front of the spar to the 'OFF' position.
8. Inform the captain that the operation is complete and that the hydraulics are over to 'General Services'.

CHAPTER SEVEN

Avro Lincoln Mk II

Tankers RE.293 and SX.993

In February 1951 it was decided that Avro Lincolns RE.293 and SX.993 should be converted into tankers for evaluation trials with the Meteor MkVIII receiver aircraft. However, the installation of the refuelling equipment differed from that of Lincoln RA.657, as shown in [Fig 80](#).

All the in-flight-refuelling equipment for the transfer of fuel in these two aircraft was within the aircraft's bomb-bay.

However, the hose-drum unit was a Mk XI type originally designed for the Boeing B-29 Superfortress three-point tanker.

Similar to Lincoln RA.657, the two 600-imperial-gallon cargo tanks were installed at the forward end of the bomb-bay, fuel also being taken from the port No. 1 inner wing tank.

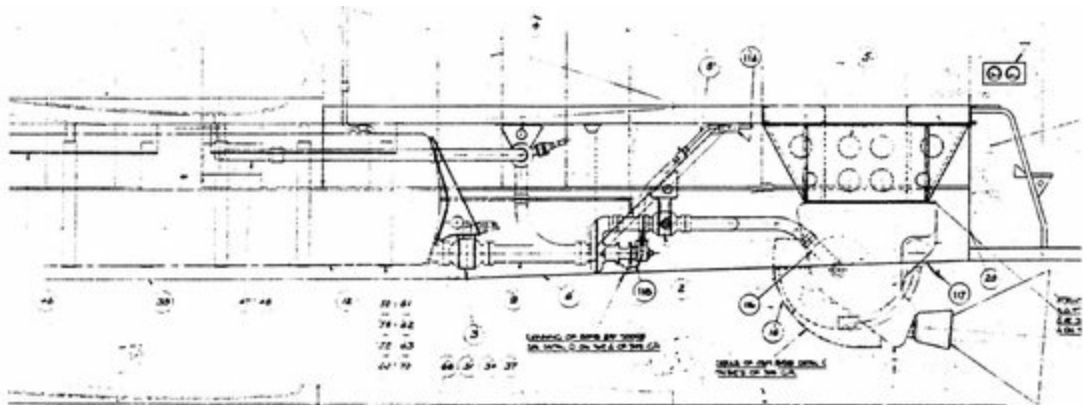
Likewise the fuel and modified hydraulic systems were the same, the only difference was the revised location of the hose-drum unit. The latter was mounted to a light alloy prefabricated box structure secured to the roof of the bomb-bay at the aft end, and protruded beneath the bottom line of the bomb-bay doors, these having a cut-out round the unit. A prefabricated fairing was attached to the front of the hose-drum unit with an air duct providing ram air to the oil cooler.

Aircraft SX.993 was, as previously mentioned, only used

briefly in the evaluation trials, and RE.293 had only just completed its initial flight testing when the 'Grand Finale' was to take place. However, owing to the political situation all was abandoned and the trials were over.

All the aircraft were returned to service after being converted back to standard.

Fig. 80. Installation of equipment in bomb-bay of RE.293 and SX.993



CHAPTER EIGHT

Boeing B-29 Superfortress:

'Looped Hose' Tanker Conversion to the 'Probe and Drogue' System

To overcome the urgent need for tanker aircraft in the Korean theatre in 1951, six Boeing B-29M Superfortress looped hose tankers were sent to Tarrant Rushton for emergency conversion to the probe and drogue system. Flight Refuelling Ltd had earlier experience of converting this type of equipment, together with improvements of the control features, and the necessary modification and additions were carried out.

Because the Jack and Heinz D.9 gearbox fitted to the existing Mk I hose-drum unit provided a very low wind-in speed for the refuelling hose, it was necessary to change the gear ratio. The change in ratio stepped up the maximum wind-in speed by approximately 4.5:1, and was effected by making inoperative the 3.4:1 epicyclic stage within the gearbox and replacing the 14-toothed sprocket fitted on the end of the hose-drum lay shaft with an 18-toothed sprocket. Owing to the change in sprocket size, the driving chain was also increased in length by two pitches.

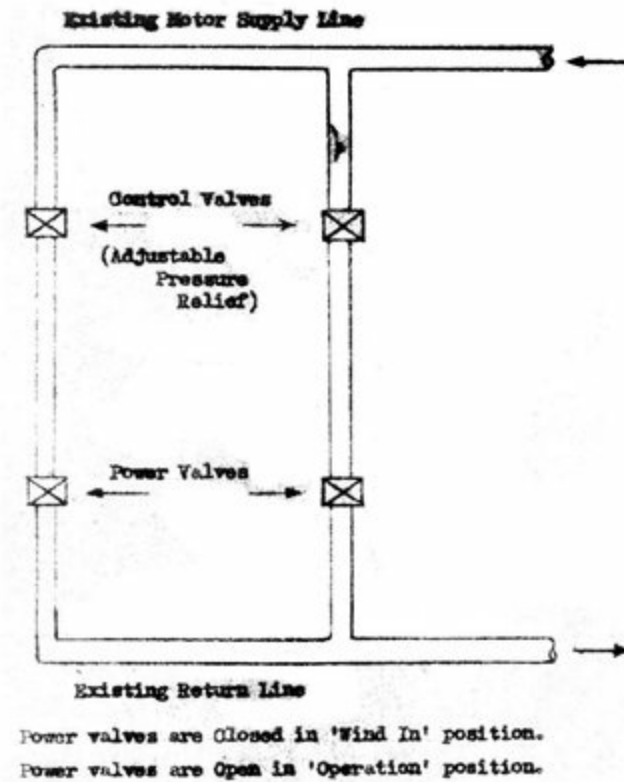


Fig. 81. Modification to hydraulics

The epicyclic stage of the gearbox was made inoperative by the removal of the sun gear and the three planets from their carrier. A steel Y-shaped driving member was inserted in the carrier and picked up the planet gear pins. The centre of the driving member was machined out and slid over the engaged sun gear shaft. Thus, when the sun gear shaft rotated, the planet carrier would rotate at the same speed.

An additional hydraulic panel was fitted to the left-hand side of the existing control panel. The new panel contained two adjustable control valves and two power valves, the outlet of each valve being connected to the inlet of its individual power valve. The motor control valve was removed from the existing panel, and the hydraulic pipes which fed it were joined together. Thus, the hydraulic motor was fed with the full output of the hydraulic package's pumps. However, at approximately the point where the hydraulic lines where the

motor control valve had been situated, two tee-pieces were placed in the line and connected to the inlet side of the new valves (Fig 81). These control valves were adjustable pressure-relief valves, and so by varying the adjustment the hydraulic oil pressure, and therefore the torque of the motor, could be varied.

Each power valve had a two-position manual control, being termed OPERATIONAL and WIND-IN. With the two valves set to OPERATIONAL, hydraulic fluid was allowed to pass through the valves and back to the hydraulic reservoir to which the valve outlets were connected. If, however, the power valves were moved to the WIND-IN position, the bleed back to the reservoir was cut off and full power was therefore applied to the motor. The power valves and control valves were duplicated to reduce the back pressure in the return line when the hose-drum unit was winding out against the action of the motor torque; i.e. the valves passed the normal output delivered by the hydraulic package plus the fluid displaced by the motor acting as a pump.

It was important to know that the modifications and additions to the hydraulic system were made so that a reasonable degree of control could be effected over the hydraulic motor, which was always tending to wind in the refuelling hose.

The variable pressure bleed would therefore allow the refuelling hose to be worked by the receiver aircraft, and took the place of the fluid drive coupling fitted to later types of hose-drum units specifically designed for the probe and drogue system.

The pawl stop mechanism, which was previously manually operated, was modified so that its action was automatic. The slots cut in the hose-drum flanges, and the shape and position of the pawl stops, remained unaltered. But a lever assembly was now pinned in an approximately central position on the pawl-stop rotating cross-member. The lever

assembly was attached at its upper end to two return springs, so that under static conditions the pawls were engaged within the drum flange's slot.

The lower end of the lever was slotted, and received a pin that located and secured the operating arm of an electrical linear actuator. The actuator was of the Rotax A.0205 type, mounted on the back face of the existing control panel. The action of the actuator was such that when it was energized it pulled against the pawl return springs, and held the pawls out of engagement. The control of the actuator arm was governed by a microswitch assembly, described later.

The end of the actuator arm was located in the lever assembly slot, and had a spring relief mechanism incorporated to prevent damage occurring to the actuator in the event of a rapid pawl engagement.

An emergency device was included in the unit should the actuator fail and hold the pawl stops out of engagement. This mechanism is described in a later paragraph, and its action was controlled by the number of turns of refuelling hose left on the drum. In the event of an actuator failure, the emergency mechanism would operate and withdraw the pin that secured the actuator arm to the lever assembly, thus allowing the return springs to snap the pawls into engagement.

Modification to the fuel system was of a minor nature in that the 1½-inch inward relief valve fitted to the right-hand side of the hose-drum unit was removed, and replaced by a Saunders ½-inch electrically actuated vent valve, the outlet of which was connected to an existing vent line. The actuator of the valve was connected through a relay to the existing actuator, which operated the Saval-type main fuel valve within the line. This interconnection was made so that the Saval-type valve was closed and the vent open, and vice versa. The operation of the actuators was normally controlled by the introduction of a microswitch assembly

that is described later, but a manual override switch was provided that closed the fuel valve and opened the vent; it also de-energized the pawl stops' actuator, allowing the stops to engage in an emergency.

Two contact lights were added to the aircraft, and were mounted on a platform on the forward wall of the hose-drum bay. These lights were similarly coloured AMBER and GREEN to those previously described, and were visible to the receiver pilot.

The microswitch assembly was the same as that employed on the Mk XI hose-drum unit on the Boeing B-29 Superfortress three-point tanker, and the assembly controlled the pawl stops' actuator, the two contact lights, and the emergency pawl stop mechanism.

The assembly was mounted on the left-hand side of the hose-drum unit over the end of the hose-drum shaft. Originally the end of the shaft had a manual winding claw fitted, but this was removed and parted off, leaving a length of 1¼ inches with a milled slot across its face. The milled slot received one end of a universal coupling.

To achieve the installation of the microswitch assembly it was necessary to remove the bolts that held the bearing housing for the hose-drum shaft, and replace them with countersink-headed screws. At the same time an outer gusset plate on the hose-drum structure was cut away to clear the assembly's housing. The length of the modified hose-drum shaft was left deliberately long to ensure the correct meshing of the universal coupling between the shaft and the microswitch assembly, this being achieved by the use of packing shims under the housing.

The electrical system had additional items, together with a simple modification, and is shown diagrammatically in [Fig 82](#), and an additional electrical panel was positioned at the right-hand side corner of the existing control panel, and contained three new switches, a two-positioned master

switch, a double-pole, double-throw switch marked AUTO and CLOSED, and a dimmer-switch for the contact lights.

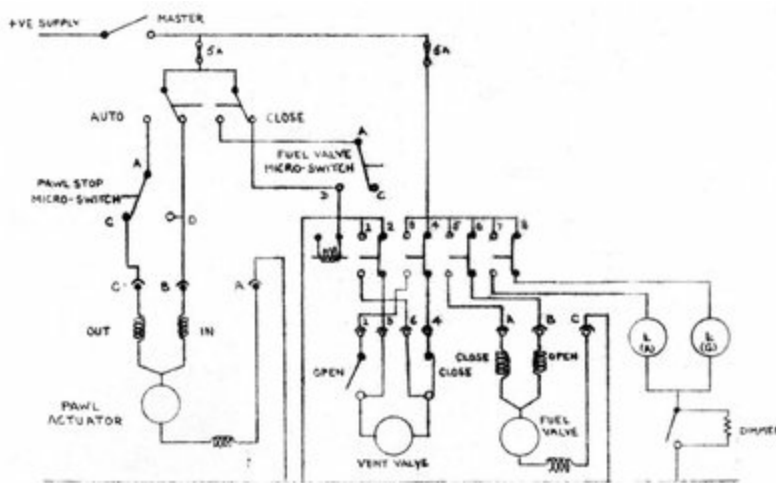


Fig. 82. Modified electrics, looped hose conversion

Operation of the master switch completed the circuit to the double-pole switch. If the latter switch was in the CLOSED position, the pawl stop actuator was energized and the pawl stops were engaged, the main fuel actuator closed the fuel valve and the vent valve actuator opened the valve, and the AMBER contact light was illuminated.

If the double-pole switch was moved to the AUTO position, the pawl stop actuator was energized, the pawl stops remaining out of engagement until the microswitch reversed the actuator. At the same time the fuel valve would be OPENED and the vent CLOSED and the GREEN contact light was illuminated.

There was an important note for operating the above switching, which was that when a refuelling operation had been completed or a ground function test had been made, a time lag of five seconds must be allowed for between switching of the double-pole switch to the AUTO position and switching the master switch OFF. This time lag allowed for

the actuators to complete their cycle of operation.

The nozzle end of the refuelling hose was modified to accept a reception coupling and drogue. The nozzle was removed and a Mk 1A reception coupling and drogue was fitted in its place by adaptation. These were similar to those used on the previous Boeing B-29 tankers.

Owing to some looped hose tankers having different fuel-pumping systems, some aircraft were equipped with six booster pumps for the transfer of fuel, while others had a Wayne centrifugal pump fitted. Those equipped with the six booster pumps had a modification to prevent an excessive build-up of pressure in the fuel line while the receiver was in contact and the vent valve closed: this was to remove one of the existing check valves in the bomb-bay and attach it to the centre pump of the rear tank. tank.

Those fitted with the Wayne pump had a fuel-pressure gauge connected to the inward relief valve mounted on the hose-drum unit. As this valve was removed and replaced by the actuated vent valve, another tapping was made in the fuel line forward of the Saval main fuel valve and connected to the pressure gauge.

A revised instruction for the use of the equipment was necessary, and the operators were advised to study the new requirement to ensure the safe and successful handling of the conversion.

The following procedure was laid down:

1. Switch ON the master switch on the small panel attached to the main control panel.
2. Select AUTO on the double switch situated on the same panel as the master switch.
3. Engage NEUTRAL on the drive selector lever situated on the main control panel.
4. Trail the refuelling hose using the hose-drum brake until the microswitch mechanism operates the pawl stops. At the same time check the operation of the contact lights.

It was important that the operator used the hose-drum brake to control the speed of the trailing sequence, thereby not allowing the hose to trail too rapidly.

Prior to the receiver making a contact, the following procedure had to be carried out:

1. Select HOSE DRUM on drive selector.
2. Check that the new power valves are in the OPERATION position.
3. Switch the aircraft's hydraulic system to ALTERNATE.
4. At an airspeed indicator reading of 210 mph check that the hydraulic pressure is 750 psi. If the new hydraulic control valves have not been previously set they have to be adjusted in the following manner:
 - a. Select WIND-IN on the left power valve.
 - b. Adjust the right control valve to 750 psi.
 - c. Select OPERATION on the left power valve and WIND-IN on the right valve.
 - d. Adjust the left control valve to obtain 750 psi.
 - e. Select OPERATION on the right power valve.
 - f. Check that the hose-drum brake is OFF. THIS NOTE IS IMPORTANT.

During the contact and while fuel was being transferred, the operation of the system was automatic. As the probe of the receiver made contact with the drogue and reception coupling, and the distance between the two aircraft was reduced, the hydraulic drive would automatically wind in the refuelling hose and take up the slack. The fuel and vent valve would operate according to the length of refuelling hose trailed, and the AMBER and GREEN contact lights indicated to the receiver pilot whether the fuel valve was opened or closed.

After the operation had been completed and the receiver aircraft had broken away, the refuelling hose was at the fully trailed position, i.e. with the pawl stops engaged and the fuel valve closed.

The refuelling operator had to carry out the following procedure to rewind the refuelling hose:

1. Apply the hose-drum brake.
2. Select WIND-IN on both power valves.
3. Release the brake, and the refuelling hose will commence to wind in. The speed of wind in has to be controlled by the use of the brake.
4. When the refuelling hose is fully in, apply full brake and stow the drogue.
5. Move the drive selector lever to the NEUTRAL position.
6. Switch OFF the hydraulic system.

The following note was added to the instructions: 'If the operation of the selector lever in (5) above is found to be difficult, the hydraulic system can be switched OFF before NEUTRAL is selected.'

7. Switch OFF the master switch.

CHAPTER NINE

Vickers Valiant

Tanker Aircraft

The Vickers Valiant tanker aircraft were really the first of the Royal Air Force's operational in-flight-refuelling tankers, even though some experience had been gained some years earlier with the Avro Lincoln tankers.

The following four paragraphs have been taken from the original Air Publication 4611, REFUELLING IN FLIGHT. EQUIPMENT (VALIANT AIRCRAFT).

One of the principal factors limiting the operational range of an aircraft was its fuel capacity, particularly in the high-performance aircraft powered by turbo-jet engines. Ground refuelling during a particular mission may be impracticable in many instances, notably during trans-oceanic flights; furthermore, the weight and volume of the fuel which must be carried substantially reduces the effective military load. The advantages of refuelling in flight were therefore as follows:

1. It increases the operational range of an aircraft during a particular sortie by replenishing the tanks when a substantial proportion of the original fuel has been used.
2. It improves the ratio of useful load to all-up weight by reducing the weight of fuel carried at any given time.
3. It reduces take-off weight.
4. It enables fighter or reconnaissance aircraft to maintain standing patrols for long periods, by the elimination of 'turn-around time'.

The following forty-five Valiant Mk I aircraft were converted to Valiant B (K) Mk 1s, the serial numbers being WP.214, WZ.400-405, XD.812-830 and XD.857-875. There were also fourteen BPR (K) Mk 1s, WZ.376, WZ.380, WZ.382 and WZ.389-399; and the B Mk 2 WJ.954 was fitted with a mock-up probe for trials.

All of these aircraft were plumbed for the tanker role, but only two squadrons, Nos 214 and 90, based at Marham, in Norfolk, were operational.

The Valiant was to have the capability of refuelling other aircraft up to 40,000 feet, at 300 knots, and transfer fuel up to 500 imperial gallons (2,250 litres) per minute with 50 psi (3.40 bar) at the tanker's reception coupling and receiver's nozzle.

To convert the aircraft into a tanker aircraft, and to make the refuelling equipment easily removable, a series of conversion packages were designed, the positions of which are shown in Fig 83.

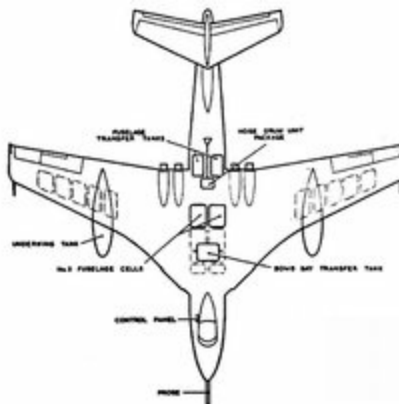


Fig. 83. Vickers Valiant tanker conversion packages

The following were the aircraft's conversion packages:

1. No. 3 cell fuel transfer pump package port.
2. Fuselage fuel transfer pump package port.
3. Bomb-bay fuel pump package.

4. Mk XVI air refuelling package.
5. Control panel package.
6. Fuselage fuel transfer pump package starboard
7. No. 3 cell fuel pump package starboard.

To achieve the required fuel flow it required Flight Refuelling Ltd to design new equipment capable not only of meeting the requirement but also of controlling it. Thus the Mk XVI refuelling package was conceived. This also meant that the parent aircraft had to be capable of supplying the fuel to the package at that flow rate, together with sufficient fuel pressure to prevent any cavitation occurring in the package's fuel pump.

The package was designated as the Mk XVI refuelling package (Fig 84 starboard side and Fig 85 port side). It became a fixed installation located at the aft end of the aircraft's bomb-bay, and its control panel was located on the starboard side towards the rear of the cockpit.

Fig. 84. Mk XVI air refuelling package, starboard side

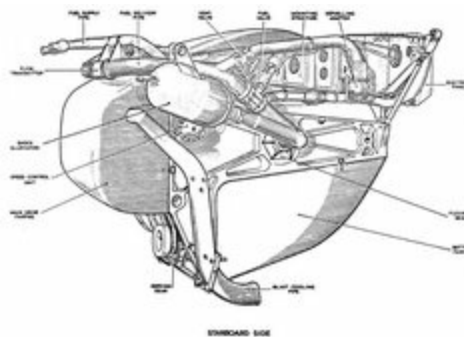
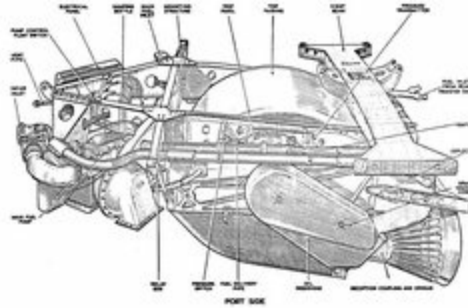


Fig. 85. Mk XVI air refuelling package, port side

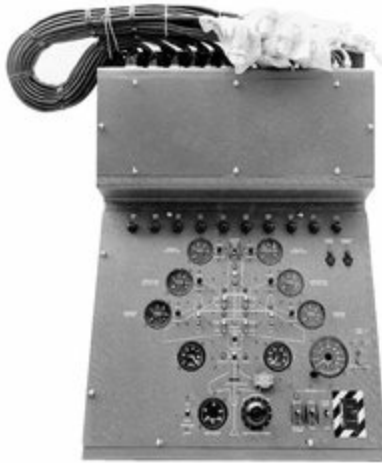


The package comprised an A-frame structure to support the Mk XVI hose-drum unit and fuel system, together with a hoist beam, and a drogue deflector attached to the hose-drum unit that incorporated twin Red, Amber and Green contact lights. The A-frame and hoist beam were the means of attaching the package to the aircraft's bomb-bay roof.

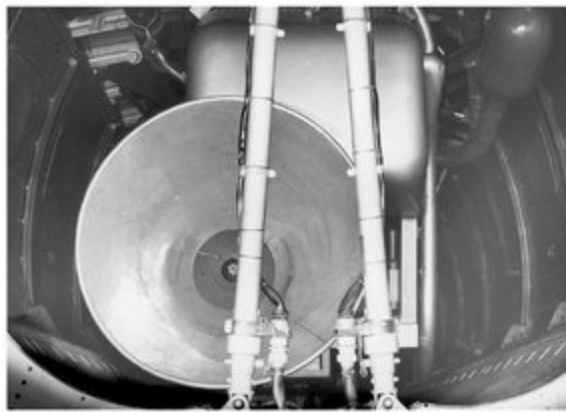
To install the package the hoist beam was attached towards the aft end of the bomb-bay roof, then the normal aircraft hoist gear was attached to the front and aft end of the package structure, then the whole package was lifted into position and secured by pippins.

To assist in the design of all the necessary interfaces, i.e. electrical, fuel, and air systems, a wooden mock-up of the package was built and installed in the prototype aircraft, as shown below. with the bomb-bay doors closed, looking forward, and bottom with the doors open looking aft typically during a refuelling operation.

The overall tanker fuel system to supply the package is shown in [Fig 86](#), and the method of achieving the high flow was by making use of the two No. 3 fuselage cells, the two fuselage transfer tanks, the bomb-bay, and the two under-wing tanks.



Mk XVI air refuelling package control panel



Mk XVI package mock-up, bomb-bay doors closed



Mk XVI package mock-up, bomb-bay doors open

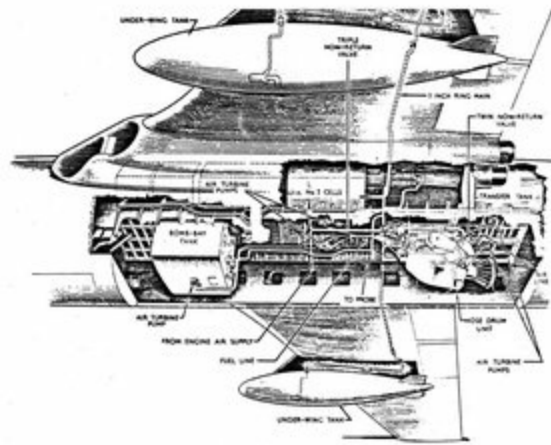


Fig. 86. Valiant tanker, overall fuel system

The tanks were fitted with immersed booster pumps, the majority of which were air turbine driven, with high-pressure air supplied from the aircraft's engine compressors at a predetermined pressure. The pumps were supplied in the form of conversion packages that comprised the pump assembly, with a hot-air gate valve and pressure-switch. A typical conversion package is shown in [Fig 87](#), illustrating a Pulsometer PAT4021, which was installed in each of the No. 3 cells, each providing a fuel flow of 67 imperial gallons (301.5 litres) per minute at 11 psi (0.75 bar).

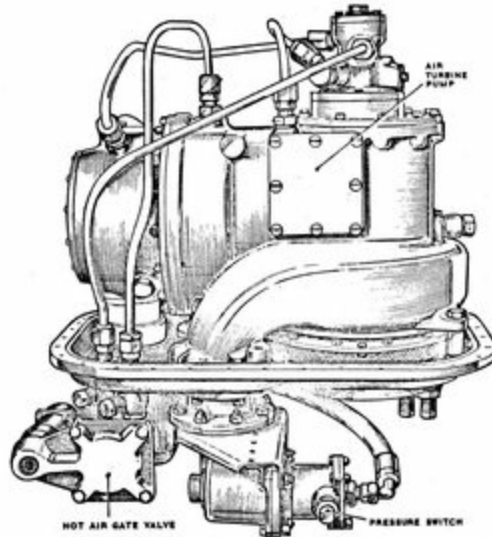


Fig. 87. Typical fuel pump package

The two fuselage transfer tanks each had a Pulsometer PAT1801-type pump, each providing a fuel flow rate of 37 imperial gallons (166.5 litres) per minute, also at 11 psi (0.75 bar). The bomb-bay tank had a Pulsometer PAT2701 at a flow rate of 60 imperial gallons (270 litres) per minute at 12.5 psi (0.85 bar). The two remaining under-wing tanks provided the remaining fuel flow by each having a 5.9 h.p. electrically powered immersed pump, this unit being similar to that employed on the Boeing B-29 Superfortress tankers; these being capable of delivering 116 imperial gallons (522 litres) per minute at 60 psi (4.08 bar). The fuel was boosted via the refuelling package air turbine fuel pump, which required 500-imperial-gallons fuel flow at a minimum inlet pressure of 5 psi to provide the 500 imperial gallons (2,250 litres) per minute at 50 psi (3.40 bar) at the reception coupling and receiver probe.

The aircraft's fuel transfer system was connected to the refuelling package via two fuel lines from the rear fuselage transfer tanks, which incorporated a non-return valve in each. Similarly, the two No. 3 cells were connected at the forward end, together with the supply line from the bomb-

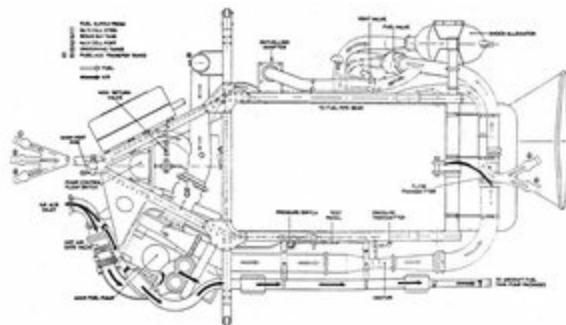
bay through non-return valves in each.

The under-wing tank's supply line, which was termed as a ring main of 3.00 inches diameter, was connected to the refuelling package, this line being located on the starboard side of the package, all the transfer lines being joined to a manifold fuel pipe upstream of the package's fuel pump.

To enable the reader to understand the total fuel system for the transfer of fuel from one aircraft to another, the refuelling package fuel system has been included in this description.

The package's fuel system ([Fig 88](#)) included the fuel, air and venting lines, together with the necessary associated equipment to transfer the fuel, the latter being mounted on brackets and lugs around the A-frame structure.

[Fig. 88](#). Mk XVI air refuelling package fuel system



The interconnections to the parent aircraft's systems were arranged to facilitate rapid connection once the package was installed in the bomb-bay.

The inlet manifold contained a wire-gauze filter to prevent any large debris entering the main fuel transfer pump, and two circular windows to enable the filter to be viewed. The fuel pump mounted on the port side of the structure was a Pulsometer 30,000 air turbine pump, as shown in [Figs 89](#) and [90](#), and was capable of developing 68 horsepower.

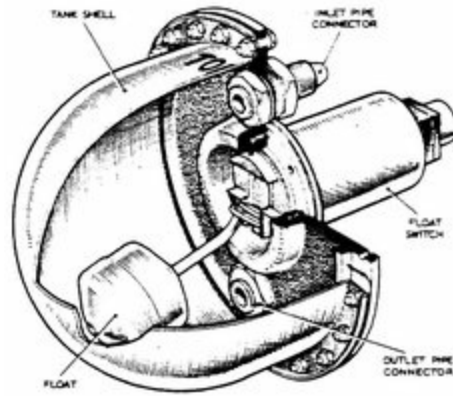


Fig. 91. Fuel pump float-switch can

To ensure that the main fuel pump would not cavitate, a pump control float-switch located in a semi-spherical can (Fig 91) was connected above and across the fuel manifold, the switch being electrically connected to the hot-air gate valve. If there was fuel in the can the electrical supply to the hot-air gate valve was connected; if, however, the can was void of fuel the electrical supply was disconnected and the main fuel pump could not operate as the gate valve would remain shut.

The fuel then passed through a large-diameter fuel pipe to a venturi, which sensed the fuel pressure at the reception coupling.

The primary control to protect the fuel pump from overspeeding was an Isospeedic governor (Fig 93), which was an integral part of the pump, the other devices incorporated for the air control being mounted adjacent to the pump; these were a Dunlop electropneumatic valve (solenoid valve), a pressure-reducing valve incorporating an adjustable needle-valve, a damping bottle, and a bellows-operated hydraulic valve. These are shown in Figs 92 to 95.

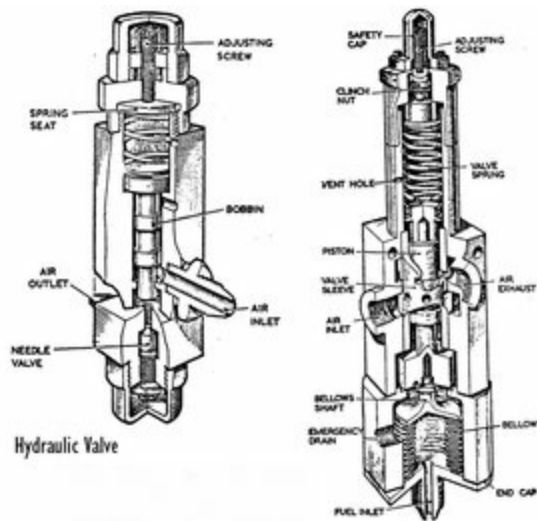


Fig. 92. Pressure Reducing Valve

The air supply, after passing through the hot-air gate valve, entered the pump's spring-loaded sleeve throttles, which were raised or lowered by the air from the control system, thus allowing the pump to increase or decrease speed.

The air for the control system was via a small tapping taken from the hot-air supply line upstream of the hot-air gate valve. The air initially passed through the pressure-reducing valve, thence to the solenoid valve and in a tapping to the damping bottle. From the solenoid valve the air line was connected to the pump's two control-valve sleeve throttles, the hydraulic valve and Isospeedic governor. The hydraulic valve was also connected at its base to the venturi throat by a small-bore pipe, the throat also having a pressure-switch connected to it.

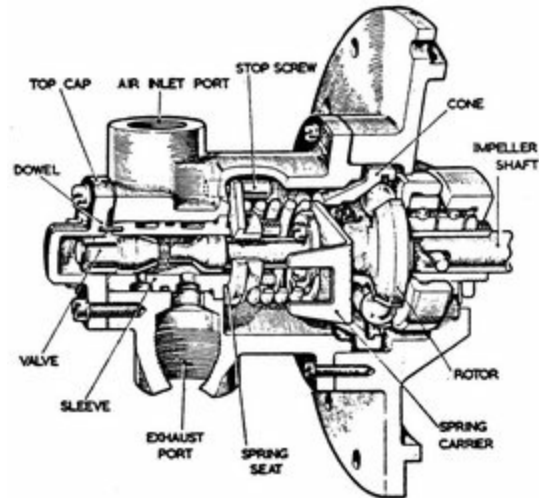


Fig. 93. Centrifugal governor

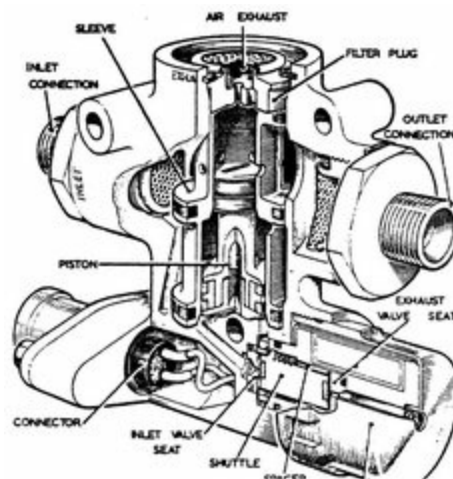


Fig. 94. Solenoid valve

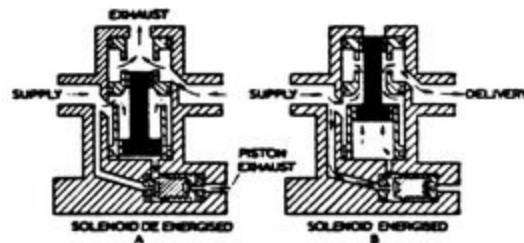


Fig. 95. Solenoid valve, functional diagram

The fuel passed from the venturi through a flowmeter, which provided an indication in the cockpit of the quantity of fuel that had been passed in pounds, thence to a fuel and vent valve, the latter being connected to the bomb-bay tank; downstream of these valves a fuel shock-absorber bottle was incorporated. At this position a rotary fuel connection was made to the hose-drum unit, and thence through the refuelling hose to the reception coupling and drogue.

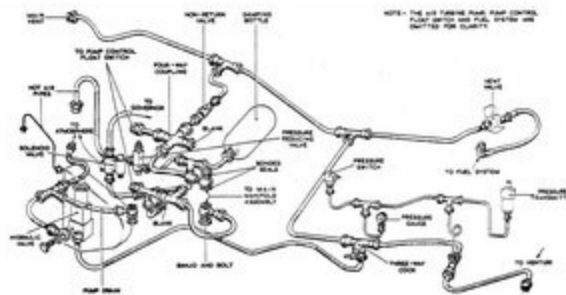


Fig. 96. Vent and fuel-pressure-sensing system

In the vent and fuel-pressure-sensing system of the package (Fig 96) the vent was connected back to the bomb-bay fuel-tank via a single pipe being joined to the aircraft's vent line at the front of the package. The figure also shows the hot air lines to the various components that controlled the fuel pumping system.

The main vent line from the forward end of the package firstly teed off to the fuel pump float-switch and the inlet manifold. The second teed off to the venturi throat, fuel pressure transmitter, fuel-pressure switch, pressure gauge and a three-way cock, and thence to the hydraulic valve, the remaining line being connected to the vent valve and main fuel system line.

The fuel-pressure transmitter was electrically connected to a fuel-pressure gauge on the operator's control panel, so that he could observe the fuel pressure at the reception coupling.

The fuel pressure gauge and the three-way cock were mounted on a test panel (Fig 97), together with a two-way electrical switch spring biased to the 'Normal' position. The panel was mounted on the port rear boom of the A-frame structure, and provided the capability of ground testing the package's fuel pump governor and the pressure-switch.

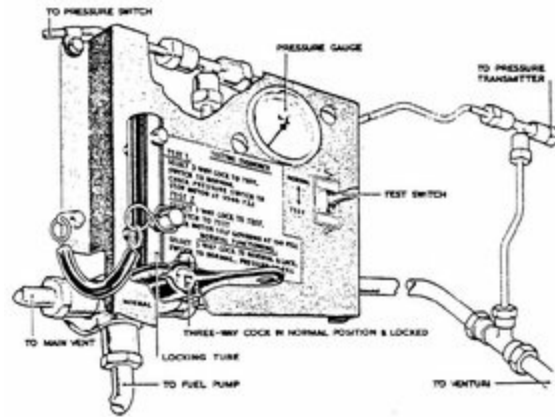


Fig. 97. Test panel

The three-way cock was locked in its operational position via a locking tube that pivoted at one end and was secured by a pip-pin at the other. When the cock was in the 'Normal' position the sensing line from the venturi was open, the connections to the pressure-switch, gauge and transmitter thus being connected. When the pip-pin was removed and the locking tube swung clear, the three-way cock turned through 90 degrees, thereby closing the venturi line. The fuel pump governor could be checked by depressing the switch, which short-circuited the pressure-switch and the governor controlled the pump. Alternatively, if the switch was left in the 'Normal' position, the fuel operating pressure could be read on the gauge. During this testing it was necessary that the fuel pump was on line, with the air supply being provided from the aircraft's engines.

When the refuelling hose was fully trailed, an indicator on

the operator's panel indicated 'REFUEL', and the hot-air gate valve was open owing to the overall automatic system. The fuel valve (Fig 98) was closed and the vent valve open. The solenoid valve was closed, its air supply port being closed and its outlet open to atmosphere, and so the tapping in the air supply line upstream of the hot-air gate valve was also closed.

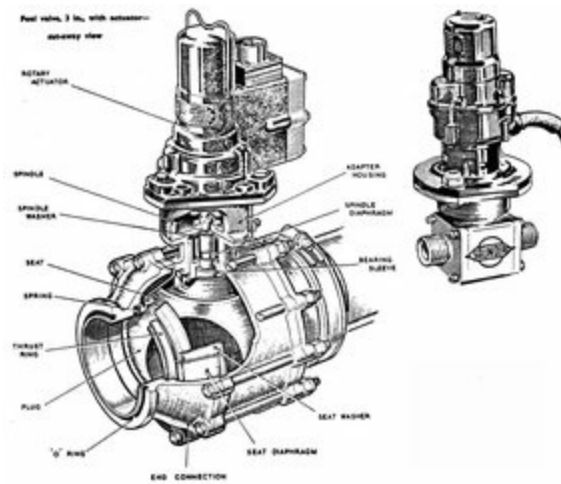


Fig. 98. Fuel and vent valves

Prior to the receiver making a contact, the contact lights (Fig 99) on the drogue deflector indicated the state of the refuelling equipment.

If the RED light was illuminated it informed the receiver pilot to stand off as the tanker was not ready. When the AMBER light was illuminated it indicated that the receiver could make a contact.

When a receiver aircraft made a contact, the valves in the reception coupling and receiver's probe nozzle were opened automatically. The receiver pushed the hose back on the hose drum, the fuel valve was opened and the vent valve closed, the GREEN light was illuminated, and the solenoid valve outlet was closed, allowing the hot air to pass through the reducing valve and its needle-valve, and thence through

the solenoid valve to the cavities beneath the fuel pump's control-valve sleeve throttles (see [Fig 100](#)).

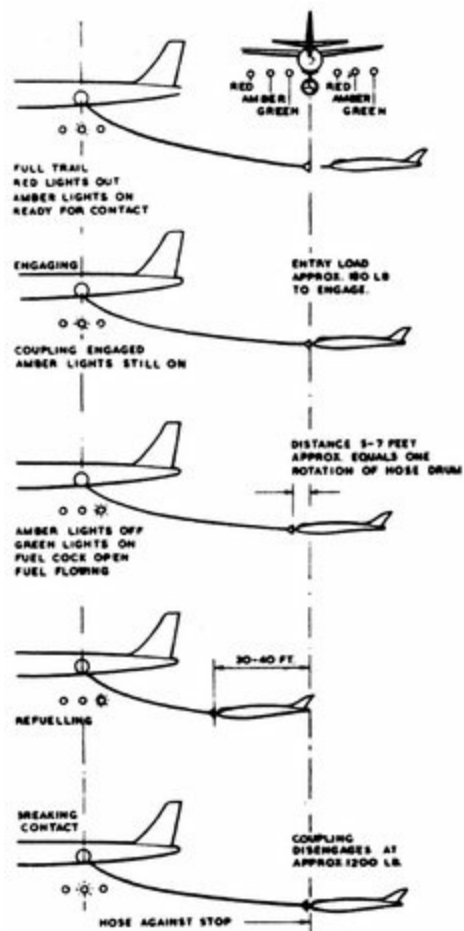


Fig. 99. Valiant tanker contact lights

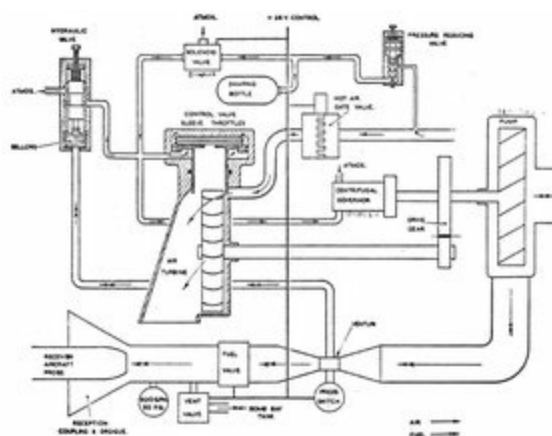


Fig. 100. Functional diagram, fuel pumping and control system

The pressure-reducing valve was set to bleed off the excess air if the pressure applied to it exceeded 40 psi. The damping bottle merely acted as a pneumatic reservoir, which was alternately charged and discharged as the air pressure at the reducing valve outlet rose and fell, thus damping out any transient surges.

The hot air pressure was therefore applied to the underside of the pump's control-valve sleeve throttles, raising the two sleeve throttles against their springs, their skirts being lifted off their seats and allowing the air through a nozzle plate to the turbine rotor. The spring-loaded sleeves were thus allowed to float as long as air was available from the solenoid valve, and they acted as servo-controlled sleeve throttles. When the tanker aircraft's booster pumps were running, the fuel flowed through the refuelling package's fuel pump inlet manifold at a flow rate dependent on the type of aircraft and the number of receiver transfer tanks in use. In a typical case the rate of flow would be 500 imperial gallons (2,250 litres) per minute, and the pressure at the inlet manifold in the order of 7 psi (0.5 bar). The system of fuel-pressure control was based on the venturi interposed in the package's main fuel line. When the fuel pump was operating, the fuel pressure at the end of the refuelling hose (and hence at the receiver aircraft's probe nozzle) was normally 50 psi (3.4 bar). The pipe from the throat of the venturi to the fuel inlet port of the hydraulic valve enabled the fuel pressure sensed at the venturi to be transmitted to the bellows of the hydraulic valve, which was so connected that when the fuel pressure rose above the predetermined value for which the valve was adjusted, the air under the control-valve sleeve throttle was progressively relieved to atmosphere.

As each fuel tank in the receiver aircraft was filled and its

shut-off valves closed, the back pressure in the refuelling hose and package fuel line was increased. This increase was sensed at the venturi and applied to the bellows of the hydraulic valve, the operation of which caused more air to be bled off to atmosphere. The air pressure at the control-valve sleeve throttles was consequently reduced, and so the throttles tended to fall and reduce the air to the air turbine, thus slowing down the pump. In the opposite case, i.e. when the receiver aircraft tanks were not fully replenished, the supply in the tanker aircraft's transfer tanks was so much reduced that the pressure at the manifold inlet fell, and cavitation would occur. The reduction of the load on the pump impeller would cause the pump to speed up, and the centrifugal governor, which was operated directly by the pump shaft, then took control, as its inlet port was connected to the air outlet of the solenoid valve.

When the receiver broke contact, the pull on the hose extended it to the full trail position. The fuel valve closed automatically; and the vent valve opened, the solenoid valve was de-energized, and the air pressure under the control valve sleeve throttles was bled off to atmosphere. No air could pass into the control-valve sleeve throttles, thus closing the air inlet and stopping the turbine.

However, as the receiver pilot had control whether he remained in contact or broke, he could carry out an emergency break at the maximum fuel flow rate. This caused a fuel surge within the package's fuel system that occurred in milliseconds, this being a high transient fuel pressure. To safeguard the tanker's fuel system, a shock alleviator ([Fig 101](#)) was incorporated in the package's fuel system adjacent to the hose drum's fuel inlet, thus absorbing the high fuel pressure.

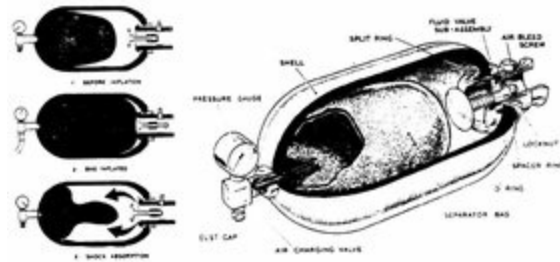
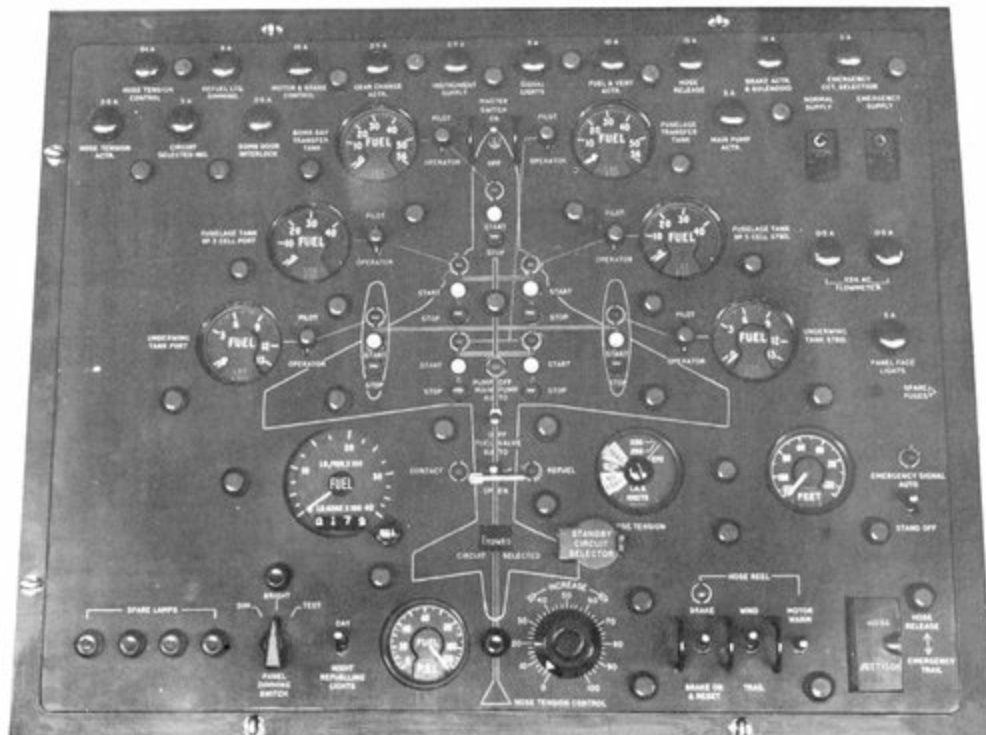


Fig. 101. Shock alleviator

The control panel (Fig 101) was supplied as a separate package, with the necessary leads and connectors to facilitate rapid installation when an aircraft was converted to a tanker aircraft. It provided the necessary controls for operating the Mk XVI refuelling package, and was mounted on the starboard side of the pressure cabin (cockpit) forward of the escape hatch, in the position normally occupied by the camera control panel in PR aircraft.

Detail of Mk XVI package control panel



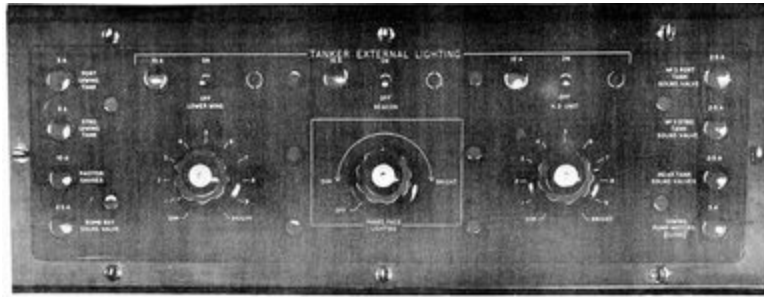
The layout of the front panel is shown in Fig.... An outline of the aircraft is engraved in the centre of the panel, and leader lines indicate the appropriate warning lights and contents gauge for each of the fuel-tanks. Separate stop and start push-button switches, with warning lights, are provided for the pumps in each of the No. 3 cells, fuselage rear-transfer cells, under-wing tanks and the bomb-bay tank. The Pacitor fuel gauges indicate the amount of fuel available for transfer from each tank, but the rate of flow and total weight (in pounds of fuel pumped) is shown on the 'Fuel rate and total flow' indicator near

the lower left-hand corner of the panel. The fuel gauges are duplicated on the pilot's panel OR the operator's control panel according to the setting of the 'Pilot/Operator' change-over switches on the latter. A footage indicator showing the length of hose wound on the hose drum, and a fuel-pressure gauge, are also mounted on the panel.

An auxiliary panel (below) incorporated the controls for the special external lighting used on the Valiant tanker, a dimmer-switch for the panel lights and eleven fuses. At the top left and right are switches that control the lower wing floodlight for illuminating the hose when trailed, and the hose-drum unit floodlight. A switch at the top centre controls a rotating beacon by which the tanker is identified during night operations.

The receiver aircraft, to be capable of receiving fuel through the air refuelling system, had initially to be equipped for ground-pressure refuelling. The only additional equipment required was a probe, which consisted of a forward-facing tubular structure fitted with a special nozzle and fuel line mounted in such a position that it was clearly visible to the pilot. The probe could be either a fixed or retractable assembly. The fuel line within the probe assembly only had to be connected to the existing ground-pressure refuelling gallery the aircraft to be automatically connected to all the aircraft fuel tanks.

Auxiliary panel



The Valiant's refuelling probe was mounted on the nose of the aircraft, the fuel line being mounted externally to the rear of the pressure cabin, thence into the fuselage.

Originally the tanker and receiver aircraft were fitted with the British Mk 6 reception coupling and probe nozzle respectively. This was the first automatic equipment that opened its internal fuel valves on the receiver making a contact.

However, the Americans in 1961 were using their MA.2 reception coupling and probe nozzle with their naval aircraft, and it was the intention to carry out a joint exercise with the Royal Air Force. Obviously there was an incompatibility problem with the two systems, and a competition for which system was to be used was arranged. Eventually it was decided to incorporate the American MA.2 equipment onto the Valiant's air refuelling equipment. Nevertheless, when the equipment was introduced it was designated as the Mk 8a reception coupling and probe nozzle for British use. These are fully described in the Mk XVI air refuelling package.

Valiant Tanker Demise

VALIANT B (K) Mk 1

WP.214	A&AEE/138 BCDU to 7486M		28-5-67
WZ.400	138 BCDU	SOC	1-1-67
WZ.401	138/207	SOC	5-5-65
WZ.402	138/207 Marham	SOC	1-3-65
WZ.403	207B Marham	SOC	1-3-65
WZ.404	207	SOC	1-3-65
WZ.405	203/138/232OCU	SOC	4-3-65

VALIANT B PR Mk 1

WZ.376	Makers	Flight refuelling trials not delivered.	
WZ.380	543	SOC	3-3-65
WZ.382	543	To 783 M	3-3-65
WZ.389	138/7/543	SOC	3-3-65
WZ.390	214		1-3-65
WZ.391	543	SOC	3-3-65
WZ.392	543	SOC	3-3-65
WZ.393	214/90/148	SOC	3-3-65
WZ.394	543	SOC	3-3-65
WZ.395	214/148/148/214	SOC	1-3-65
WZ.396	543	Undercarriage jammed up, belly landed Manston	23-5-64
WZ.397	214/543	To 7888M	4-65
WZ.398	543	Destroyed in Hangar fire, Wyton	13-9-57
WZ.399	543	Abandoned take-off, overshot runway on railway line, Offut. AFB, Neb	3-11-61 DBF

VALIANT B Mk 2

WJ.954 Makers and A&AEE Retained by makers FF.4-9-53 to PEE 2-7-58

Key

SOC Struck-off-charge BCDU. Bomber Command Development Unit.

OCU Operational Conversion Unit A&AEE Aircraft and Armament Experimental Establishment, Boscombe Down

CHAPTER TEN

Armstrong Whitworth Argosy

Tanker/Receiver

The Argosy tanker aircraft XN.814 conversion was for trial purposes only, the conversion being agreed in January 1964 by the Ministry of Aviation.

The feasibility study of April 1963 investigated three proposals. The first was to convert the aircraft using three Flight Refuelling Ltd POL (Portable Overload) fuel-tanks and a variant of the Mk 20 refuelling pod. The second was the use of the Argosy standard long-range fuel tanks and a variant of the Mk 20 refuelling pod. And the third proposal was to extend the range of the Argosy by using two Flight Refuelling Ltd POL fuel-tanks.

The following only describes the in-flight-refuelling proposals.

Initially the position of the refuelling pod on the port side of the aircraft had to be defined, and this was achieved through the hose and drogue trailing angles at the refuelling airspeeds from existing aerodynamic data on hose trailing angles. However, the initial trailing angle of 11 degrees was altered to 16 degrees because of the aircraft's maximum speed of 180 knots IAS caused by the aircraft's aileron characteristics for manoeuvrability during the refuelling operation, thereby causing the hose to fly at a lower angle. The variant refuelling pod had a major modification to the rear end fairing, which had the drogue tunnel offset from the centre line, thus ensuring that when the hose and drogue

were wound in, the drogue would not impinge on the fuselage skin. This was necessitated by its installed position on a fuselage pylon mounted to the port side of the aircraft's fuselage, and was designated as the Mk 20D refuelling pod, as shown in [Fig 102](#) The pod would be capable of transferring fuel at 150 imperial gallons (675 litres) per minute, and so this was the flow requirement from the tanker.

The pylon to support the refuelling pod ([Fig 103](#)) was of a triangular shape consisting of a single-cell torsion box, having a main rear web, two central ribs and end ribs having a forked end attachment secured to them. These enabled the pylon to be secured to frames 23, 24, and 25 of the fuselage. These were enclosed by a thick alloy skin, which had stringers attached to it internally on its top and bottom surfaces. On the underside of the pylon assembly a ¼-inch-thick sole-plate provided the locations for the refuelling pod's air vent, fuel electrical connections, the main suspension point and fore and aft spigots.

To enable the aircraft's fuselage to accept the loads generated from the refuelling pod through the pylon into aircraft's structure at frames 23, 24 and 25, it was necessary to reinforce this area locally. This was achieved by the incorporation of a 0.040-inch-thick doubling plate and 0.064-inch-thick channels, together with a machined fitting at each aircraft frame. External to the fuselage a 0.040-inch-thick doubling skin was riveted to the existing structure, and on top of this at each frame were machined brackets that were bolted through the fuselage frames and skinning to accept the pylon's attachments.

[Fig. 102](#). Flight refuelling pod Mk 20 installation

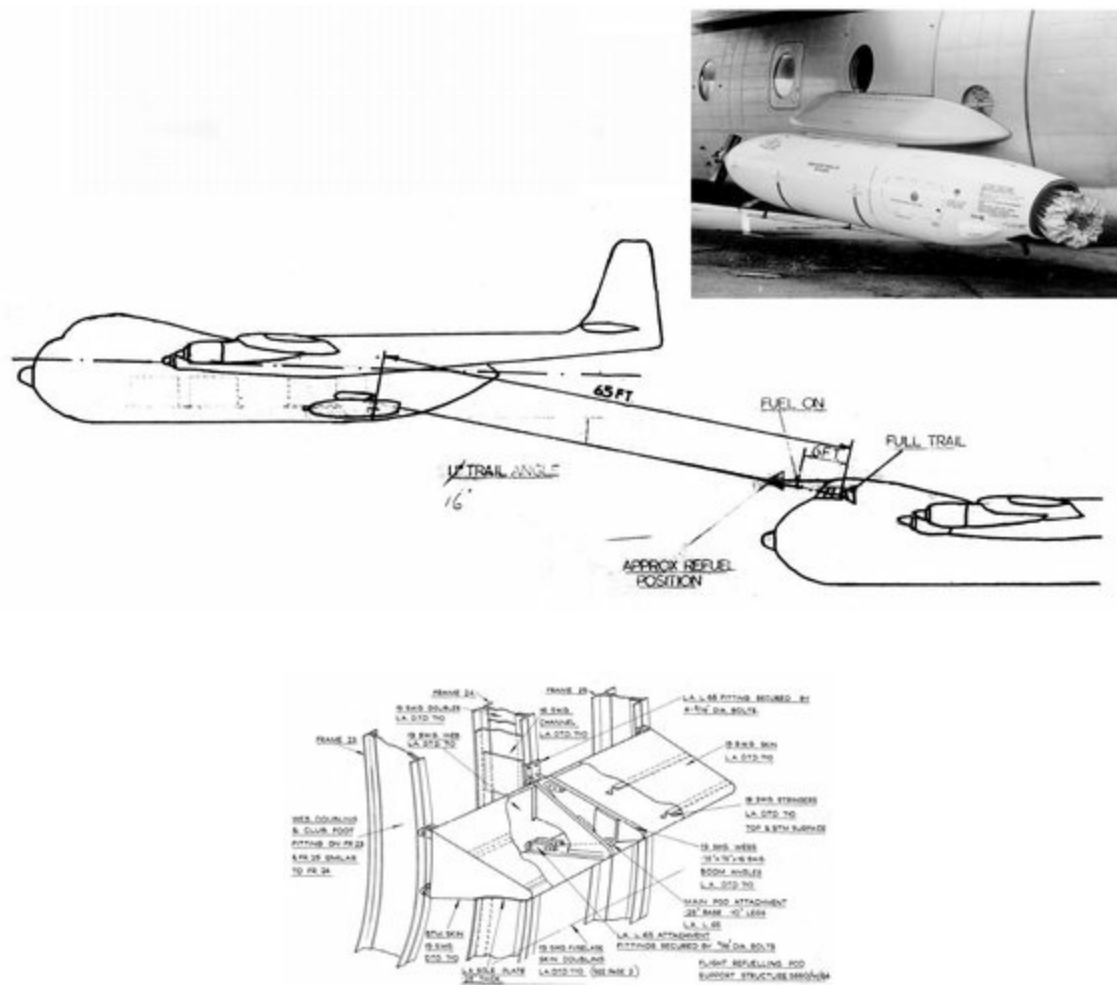


Fig. 103. Support Pylon

The fuel, air vent, electrical, suspension lug and fore and aft spigot interfaces between the aircraft and pod are shown in [Fig 104](#), together with the method of hoisting the pod into position before pre-loading. The hoisting winch was a standard manual winch attached to the side of the fuselage.

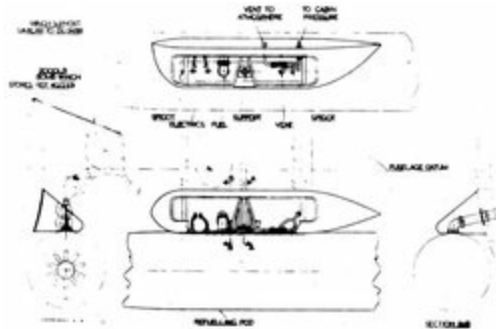


Fig. 104. Interfaces

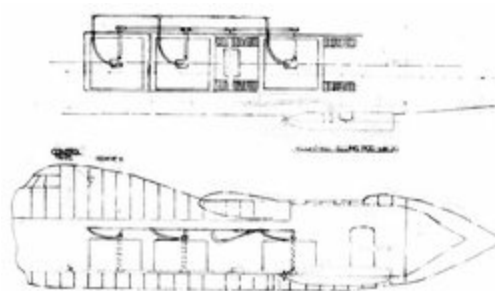


Fig. 105. Tanker installation.

The overall tanker installation using three Flight Refuelling Ltd POL tanks is shown in Fig 105. These would provide a total of 2,300 imperial gallons (10,350 litres) of transferable fuel.

Although the figure of the extra fuel tanks shows three POL tanks, there was a second option of incorporating either one or two tanks, this being dependent on the tanker's operational requirement. Each tank had the capacity of 770 imperial gallons (3,465 litres) of transferable fuel, and was mounted on a standard freight pallet which could be transferred into the aircraft via a standard roller conveyor system.

The fuel system is shown in Fig 106 with three tanks installed. These were connected together by a 3.00-inch fuel line to supply the refuelling pod via an inline fuel pump, this

line also being connected to the aircraft's fuel system, thus permitting the POL tanks to be replenished. Within each tank supply pipe was a high-level float-operated refuelling valve, which closed the supply line when the fuel had reached a high level, and a non-return valve that closed when the tank was being replenished, allowing the fuel to flow through the valve and open when supplying the pod; there was also a foot valve at the bottom to prevent the in-line fuel pump cavitating when the fuel reached a low level.

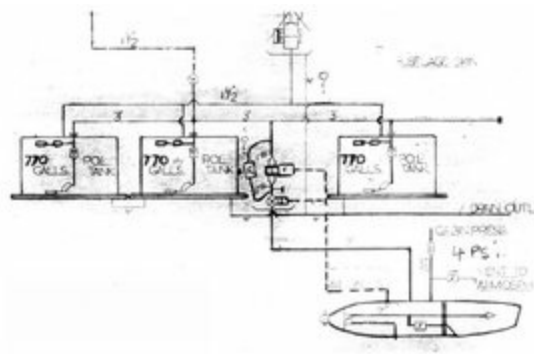


Fig. 106. Fuel System.

The in-line fuel pump was a Dowty Rotol Ltd twin-cell pump driven via an explosion-proof electric motor. The basic pump had been developed from a Dowty Rotol fuel proportioner Type 6.1602.0002, which had also been adapted to use the electric motor in lieu of a hydraulically powered motor. The pump had a minimum output of 9,000 imperial gallons (40,500 litres) at 150 gallons (675 litres) per minute at 5 psi (0.034 bar); or 9,600 imperial gallons (43,200 litres) at 160 gallons (720 litres) per minute at 4 psi (0.027 bar). The pump pulled fuel from the POL tanks that was transferred to the refuelling pod through an actuated cock, being controlled via the high-level float-switch within the pod that automatically closed when the pod was full.

The transfer fuel flow rate would therefore be approximately 156 imperial gallons (702 litres) per minute,

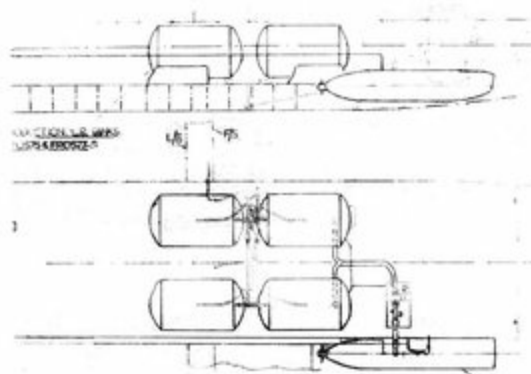
which would entail a slight fall in the fuel level within the pod, thus preventing undue hunting of the actuated cock via the pod's high-level float-switch. A manual override was provided for the actuated cock at the cock and at the engineer's panel in the cockpit.

All the tanks were connected to a common vent line, which was proposed to be connected to a differential pressure-vent valve. Similarly the two forward tanks were connected with a small drain line, the rear of the second tank to the rearmost tank and thence to a drain outlet.

There was a standard Mk 20 refuelling pod control panel on the flight deck adjacent to the flight engineer's station.

The POL tanks could be refuelled on the ground via a hose through the rear freight doors. The flow rate into the tanks was controlled by restrictors to a maximum of 100 imperial gallons (450 litres) per minute, and the high-level float-valves cut off the supply to each tank as it became full.

Fig. 107. Fuel system diagram



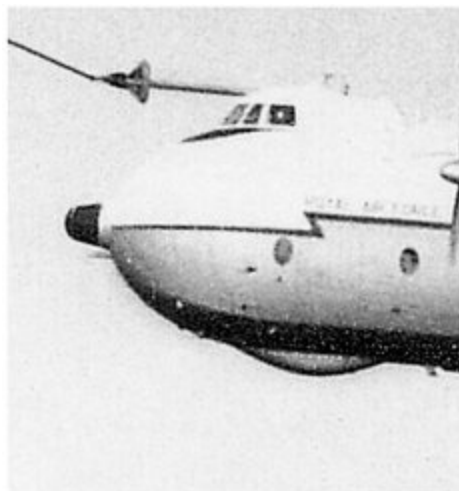
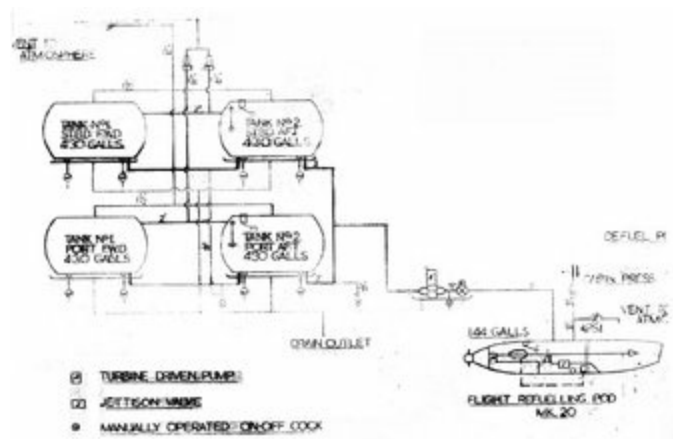
As an alternative to the use of POL tanks as fuel containers for the tanker role, the use of four existing long-range tanks, type FR0570, were proposed, as shown in [Fig 107](#).

The long-range tanks were standard, with the exception that the submerged fuel pumps were removed, and the fuel

pump required to transfer the fuel to the pod was a Dowty Rotol 6.0001.520, which was installed externally alongside the tanks.

The roller conveyor and side guidance system was not required with this installation, which had built-in castoring to facilitate installation and removal. Each tank contained 430 imperial gallons (1,935 litres), thus providing 1,760 imperial gallons (7,920 litres) of transferable fuel. The fuel system using these tanks is shown diagrammatically in [Fig 108](#).

Fig. 108. Fuel system



Argosy receiver

The Mk 20D refuelling pod control panel was a standard Mk 20 type that was installed at the flight engineer's position on the aircraft's flight deck.

The Argosy receiver aircraft, as shown above, had its refuelling probe installed above the flight deck and slightly to the starboard side of the fuselage. The probe structural outer tube had the Flight Refuelling Ltd Mk 8 probe nozzle secured to it, while the inner fuel line was connected to the aircraft's ground-pressure refuelling system.

The trials were successfully carried out, but nothing came of the conversion and the aircraft reverted to standard.

CHAPTER ELEVEN

Mk VII Series I

Hose-Drum Unit

The Mk VII Series I hose-drum unit ([Fig 109](#)) comprised the following components:

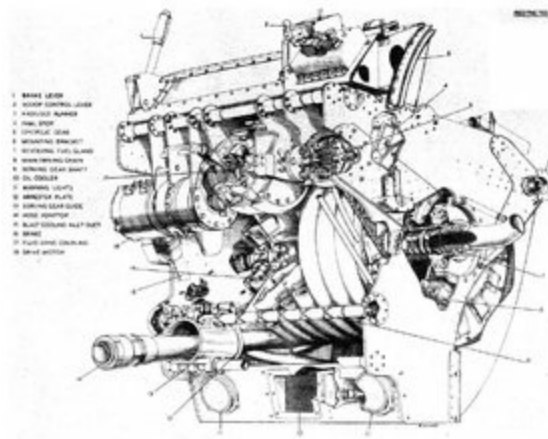


Fig. 109. Mk VII Series I hose-drum unit

1. Hose-drum.
2. Drive system.
3. Serving gear assembly.
4. Hose-drum control panel.

The hose-drum unit structure was similar to that of the Mk XI described in the Boeing B-29 Superfortress three-point tanker, having two reinforced side plates joined together by tubular members, to which were attached at the forward end two pivot trunnions for retraction purposes. The trunnions

were secured to two housings, one on either side of the unit containing ball bearings that were mounted to the aircraft's fuselage floor.

Approximately in the centre, and at the top of each side plate, a housing and thrust bearing was fitted to receive the ends of a retracting tube assembly. The assembly consisted of a tubular member, on the centre of which was pinned an adjustable yoke internally threaded to accept the end of a hydraulic ram.

The left-hand side plate included a similar brake to that of the Mk XI unit, together with a bearing housing, cover plate, and the mounting for a microswitch assembly. Similarly, at the lower rear end of the side plate were housings for the serving gear mechanism.

The right-hand side plate was of a similar design to that of the left, and provided the mountings for the rotating fuel joint, drum bearing and chain sprocket, together with the bearing housings for the serving gear mechanism.

The hose drum had a 16-inch-diameter barrel and two side flanges. The barrel comprised three magnesium alloy castings, two of which were covered with a light alloy skin. The three castings were bolted together internally and had a 28-inch-diameter flange secured at each end.

The refuelling hose entered the centre of the drum barrel on the starboard side, and was led through the centre of the first casting, termed the barrel piece, to the centre of the middle casting, or the barrel small end. The hole through which the hose was led was a spiral form, so that, at the point where the third casting, or barrel large end, was fitted the hose lay along the inner wall of the drum. The third casting was also shaped on its periphery to receive the first coil of the refuelling hose, which was led outside the barrel adjacent to the port drum flange.

The outer face of this flange had a 9-inch brake drum

secured to its centre, which accepted the expanding shoe portion of the hose-drum brake. A spring-loaded plunger was also mounted on the inner face of the flange, making contact with the brake drum, so ensuring electrical continuity between the drum and structure.

The refuelling hose was of similar construction to that used on the Mk XI hose-drum unit, except that it was 2¼-inch bore and 81 feet in length. The adaptors for its attachment to the reception coupling and emergency slug were also similar.

However, the attachment to the rotating fuel joint differed in that the hose was secured directly to the hub of the assembly in the same manner as the looped hose system.

The hose-drum drive system was also similar to that of the Mk XI hose-drum unit, comprising an electric motor, spur gear reduction, fluid drive coupling, and an epicyclic gearbox. The complete assembly was rigidly suspended from two tubular cross-members fitted across the top of the rear end of the hose-drum unit structure. The electric motor was positioned on the left-hand side, the drive being transmitted through the spur gear reduction to the fluid drive coupling and thence to the gearbox.

The electric motor was a specially rewound generator, which had the characteristics of a DC shunt wound motor, and was rated at 5 h.p., with a line voltage of 26 volts. The cooling of the motor was by blast air, similar to that employed on previous units. The motor was not suppressed against radio interference, but two suppressors were connected in parallel, the supply cables being duplicated. The connections to the motor, therefore, were made by bus-bars that were contained within a screened housing on the port side plate adjacent to the motor.

The spur gear reduction ratio of 1.66:1 was fitted between the motor and fluid drive coupling within a cylindrical housing, the housing incorporating a lubrication nipple that

enabled oil to be fed to the gears when they were being serviced.

The fluid drive coupling was similar to those employed on the Mk IX and Mk XI hose-drum units. The oil contained within its casing was fed to an oil cooler, which was mounted on a prefabricated metal frame between the side plates on the underside of the hose-drum unit and to the rear. This permitted the cooler to face the aircraft's slipstream when the unit was lowered.

The fluid drive coupling was connected to the gearbox by a universal coupling, half of which was on the drive's output shaft, the other on the gearbox shaft. The gearbox provided a 4:1 reduction between the fluid drive and the hose drum's driving sprocket. This was achieved by two planetary gears within a planet carrier meshing with a sun gear on the gearbox input shaft, the two planetary gears also meshing with an internal fixed annular gear, the planet carrier being a part of the gearbox output shaft. On this particular unit no gear-change operation was required, as the fluid drive coupling was manually controlled by the operator. On the end of the gearbox output shaft was the hose-drum drive sprocket. This was connected to the large sprocket mounted on the right-hand-side drum flange via a $\frac{5}{8}$ -inch-pitch chain.

The serving gear assembly was similar to that employed on the Mk XI hose-drum unit. The assembly comprised an Archimedean drive shaft, a hose guide with a horseshoe-shaped arrester plate secured to it, and a microswitch assembly with a spring-loaded plunger installed on the hose guide. The assembly was driven by the rotation of the hose drum via a $\frac{1}{2}$ -inch-pitch chain-drive sprocket mounted within the microswitch assembly secured at the hose drum's hub on the port side plate, through the Archimedean shaft drive sprocket, the ratio between the sprockets being 1:1.

The pawl stop mechanism was similar to that employed on the Mk XI hose-drum unit, and was automatically applied to

limit the maximum length of refuelling hose trailed. The installation of the mechanism was the same, and operated in the same manner. The emergency mechanism, to apply the pawl stops in case of a failed actuator, likewise withdrew the pin securing the actuator to the pawl stop-lever mechanism. However, its method of operation differed from the previously used in that the screw-actuated arm, at a predetermined point, tripped a trigger arm, which in turn released a spring-loaded plunger. One end of the plunger was attached to a flexible cable secured to the pin retaining the electrical actuator to the pawl stop-lever.

The screw-actuated arm was driven via a threaded shaft attached to the outer face of the chain sprocket on the end of the serving gear's Archimedean shaft. The arm, which was turned through 90 degrees, protruded through a hole and moved across the face of a plunger housing mounted on the inner face of the left-hand side plate. Pivoted on the face of the housing was a small trigger arm, one end of which fitted into a recess machined in the screw actuator arm; the other fitted over a spring-loaded plunger, and retained the spring in compression. As the serving gear sprocket rotated, the threaded shaft and machined recess moved across the trigger end; when approximately 1½ turns of refuelling hose remained on the drum, the shoulder at the limit of the recessed portion of the arm tripped the trigger, which in turn released the spring. Similar to that on other hose-drum units, the mechanism had to be reset during ground servicing, though it was still possible to rewind the hose.

The microswitch assembly performed the same function as those on other units, but on this unit the emergency pawl stop-mechanism was not incorporated, as shown in [Fig 110](#). It typically operated the fuel and vent shut-off valves within the tanker's fuel transfer system, and likewise the GREEN and AMBER contact lights. The lights on this unit were located within a prefabricated structure at the bottom and to the rear of the hose-drum unit structure, being situated on

either side of the fluid drive coupling's oil cooler. The GREEN was on the left-hand side and the AMBER on the right when viewed from the rear of the unit.

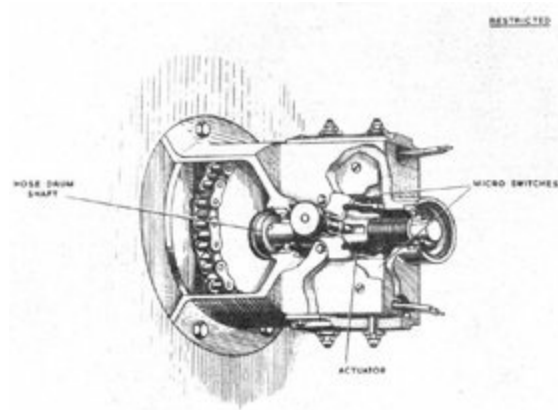


Fig. 110. Microswitch assembly

The operator's control panel was fitted to the hose-drum unit above the drive system assembly, and faced aft. On the left-hand side of the panel was the brake lever, which was connected by flexible cable to the hose-drum brake. The lever incorporated a ratchet mechanism operated by a push-button at the top of the lever. A rectangular transparent panel was fitted centrally in the panel to enable the operator to view the refuelling hose throughout the refuelling operation, and to observe that the serving gear was functioning correctly. The fluid drive coupling's scoop control was situated to the right of the transparent panel, being mounted in a quadrant graduated in degrees. The control lever incorporated a screw-locking device so that it could be locked in any desired position.

A switch box was fitted to the right of the fluid drive coupling's control lever, and housed a press-button switch for starting the electric motor of the main drive system, and also a toggle-switch for the MOTOR-OFF. Two indicator lights were also installed in the switch box—a RED light

indicating that the control panel was 'live', and a GREEN indicating that the motor was running. A second switch box was mounted above the one already described, which contained three switches, one a dimmer-switch for the GREEN and AMBER contact lights operated by the microswitch assembly, and the other two for manual control of the fuel and vent shut-off valve in the event of a microswitch failure. Of these two switches, one changed the system from automatic to manual, the other controlled the valves.

The reception coupling and drogue employed on the Mk VII Series I hose-drum unit was similar to that used on the Mk XI wingtip unit on the Boeing B-29 Superfortress three-point tanker.

CHAPTER TWELVE

Mk IX Hose-Drum Unit

The Mk IX hose-drum unit (high rate of flow) was positioned in the rear end of the three-point tanker aircraft's fuselage, and was remotely controlled from the rear pressure cabin by the master operator. The unit fulfilled a similar function as the wingtip unit in that it controlled the length of refuelling hose trailed and the response when a receiver made a contact. In this instance, however, the unit was retractable and was completely stowed within the aircraft's fuselage when not in use.

Because of the similarity between certain components and those already described in the Mk XI hose-drum unit, cross-references are made to prevent repetition. The Mk IX hose-drum unit is shown in [Fig 111](#).

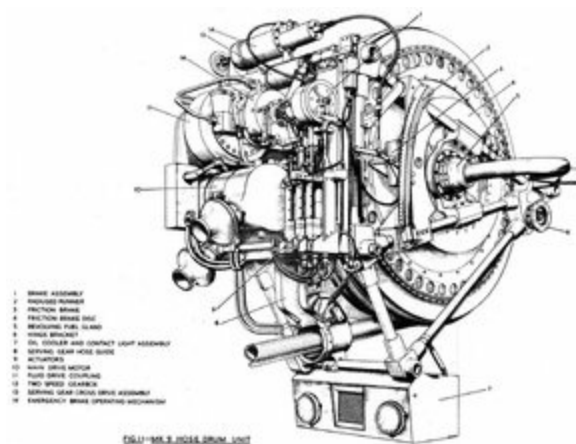


Fig. 111. Mk IX hose-drum unit

It consisted of four main assemblies, which were:

1. Frame assembly.
2. Hose drum and refuelling hose assemblies.
3. Main drive system assembly.
4. Serving gear assembly.

The frame assembly comprised two tubular triangulated side frames joined together by tubular cross-members, the ends of which were joined by light alloy cast fittings. The forward cast end fitting on each side of the assembly had a bearing stub shaft bolted to its outer face. The stub shaft located the hose-drum mounting flange and ball bearing, which, in turn, was bolted to special fittings in the fuselage, so that the unit was allowed to pivot about the mounting points.

Across the two upper tubes on each side frame, approximately at the mid-position, a drum-bearing housing was secured to them. The left-hand housing retained a self-aligning bearing secured in position by a microswitch assembly bolted to its outer face. The right-hand housing retained a single roller bearing secured by a locking-ring bolted to its outer face.

To the rear of the bearing housings, and on the same tubular members, a radiused runner was mounted to them, so permitting the engagement of spring-loaded plungers fitted to two up-lock towers positioned in the aircraft on each side of the unit. At the lower end of each runner an up-lock stop was mounted that engaged with the up-lock towers, positively locking the unit in the retracted position. The right-hand runner also had mounted on its inner face an emergency brake mechanism. The uppermost block, which retained each runner in position, had two lugs formed on its upper face, one each of which provided a connection to the two rams of the hydraulic retraction gear, the other two being for the attachment of the unit's lifting gear.

Attached to the cast fittings at each end of the rear lower

cross-member was a fabricated metal frame that housed a small oil cooler and two contact lights. The lights were positioned one each side of the oil cooler, and were coloured GREEN and AMBER, the GREEN being on the left-hand (port) side. The cross-member immediately above the member previously described had steel inserts fitted in each end so that they protruded a distance of 1.0 inch beyond the cast end fittings. These engaged with cup-shaped blocks located in the aircraft's fuselage on either side of the hose-drum unit when fully lowered.

Attached to the lower face of the main drive platform was a deflector board; which extended aft, so that when the unit was in the lowered position the rear edge of the board faced the edge of a small built-up fairing attached to the keyhole slot in the bottom of the aircraft's fuselage. The board was supported by two tubular struts shaped to clear the face of the drive platform. This deflector and fairing were fitted to prevent the aircraft's slipstream forcing the drogue up into the fuselage, thus preventing it from being trailed.

The hose drum comprised a 20-inch-diameter drum to which were attached two 42-inch-diameter side flanges approximately 13 inches apart. The barrel of the drum was a light alloy casting, shaped on its outer surface to receive the first layer of refuelling hose that entered the drum on its right-hand side, where a slot was machined to receive a special adaptor.

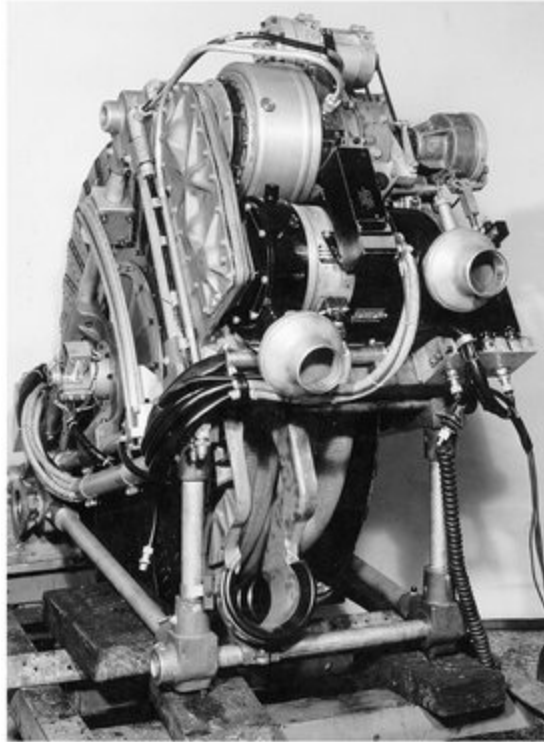
The left-hand drum flange had secured to it a reinforcing plate to enclose that side of the drum. Similarly the right-hand side also had a reinforcing plate secured to it, together with the drum's main drive-chain sprocket, both sides of the drum having cover plates attached. This side of the drum also had a distance piece nearly the same diameter as the cover plate, secured in position together with a steel friction disc that formed a part of the emergency brake mechanism. A hollow boss fitted at the centre of the cover plate accepted the drum bearing, and it was externally threaded to accept

the rotating fuel joint.

The rotating joint comprised a gland housing, compression spring, two soft and three standard SEA sealing rings, together with a retaining cap.

One end of the joint was fitted to a fuel pipe within the hose drum, the other end to the refuelling hose by the special adaptor. The gland housing was machined to accept the spring and sealing rings, and the end of the fuel line from the tanker's refuelling system, which had a sleeve soldered in position, was inserted into the gland housing, the sleeve thus bearing on the rings. The sleeve also had a shoulder machined on its outer face, which pressed on a bearing fitted at the end of the gland housing, and the retaining cap was screwed onto the boss and retained the fuel line within the gland housing, thus allowing the hose drum to rotate around the fuel line and at the same time ensured a fuel-tight connection.

The refuelling hose on the Mk IX unit was rubber lined with a woven cotton cover reinforced with a helical wire interwoven into the cover, and had a length of 95 feet (29 metres), having a bore of 2½ inches (63.5 mm). One end of the hose was attached to the reception coupling and drogue, the other to the fuel pipe within the hose drum, the reception coupling and drogue being similar to that used on the Mk XI wingtip unit. The special adaptor fitted to the hose was attached to the drum by two key plates fitted around the adaptor, which slid into machined slots formed in the drum casting. Like the Mk XI refuelling hose, the hose had a slug fitted for emergency purposes, and the painting of it was also similar.



Mk IX hose-drum unit drive system

The hose-drum drive that provided the motive power was positioned on a cast platform mounted across the rear of the unit's frame structure, as shown above, and bolted to the frame's cast end fittings.

The platform was machined to accept the following components:

1. Electric drive motor.
2. Fluid drive coupling.
3. Two-speed gearbox.
4. Brake assembly.
5. Actuator assembly.

The electric motor was positioned at the bottom right-hand corner of the platform, with the fluid drive coupling immediately above it. The two-speed gearbox was located adjacent and to the right of the fluid drive coupling, and the brake assembly at the top right-hand corner alongside the

gearbox and to the right of the drive motor. The actuator assembly was below the brake and to the right of the drive motor.

The motor was a Jack and Heinz 27 V DC motor rated at 9.50 horsepower, at 325 amps at 3,600 rpm. The motor was self-cooled, and flame traps were embodied in the air inlet and outlet ducts, and a thermal protector was included in the design to protect against an excessive overload. The motor's output drive shaft was connected to the fluid drive coupling via a set of spur gears located within a cast housing.

The fluid drive coupling on the Mk IX unit was similar to that on the Mk XI wingtip units. In this instance, however, the oil outlet and inlet pipes from the coupling were connected to an oil cooler, which was suspended from the bottom of the unit; the input shaft of which was carried on a bearing within the spur gear housing, with its output being connected to the two-speed gearbox through a universal coupling ([Fig 112](#)). It was a cylindrical light alloy casing with feet formed at its base and fitted with a cover plate. The casing contained an epicyclic train of gears providing ratios of 1:1 and 5:1.

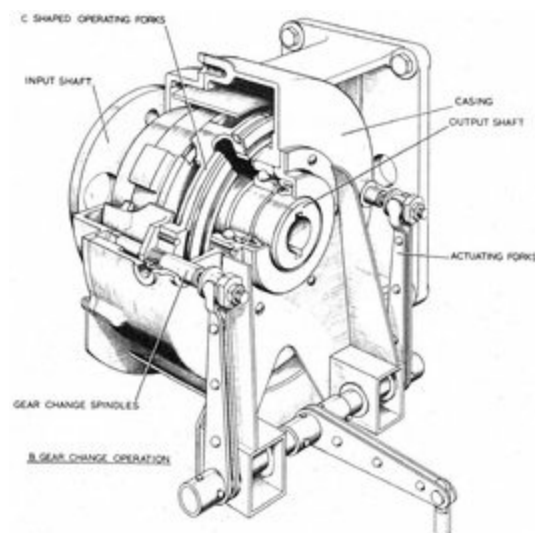


Fig. 112. Mk IX hose-drum two-speed gearbox

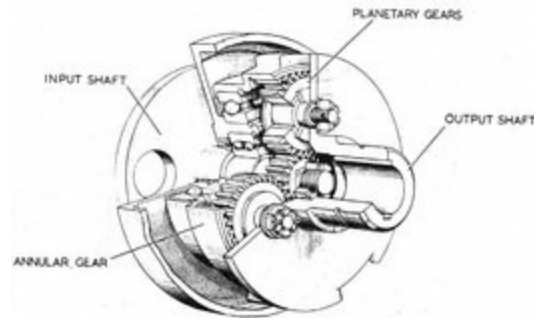


Fig. 113. Mk IX hose-drum unit, two-speed gearbox gear train

The gear train ([Fig 113](#)) comprised an input shaft, three planetary gears with a carrier, an internal toothed annular gear, a selector ring, and a half coupling or output shaft. The input shaft upon which a spur gear was keyed rotated in the casing's cover on a double-row ball bearing. The drive from the spur gear was transmitted to the three planetary gears, the carrier of which was integral with the output shaft, and was located on a single-row ball bearing, both shafts having oil seals situated within the cast casing, thus preventing any oil leakage.

The internal toothed annular gear, which was in constant mesh with the planetary gears, was located on a single-row ball bearing. On the outer face of the planet carrier were two slots, and similarly on the outer face of the annular gear dogs were machined, these slots and dogs being with one another and diametrically opposed on their respective components.

Two gear-change spindles, also diametrically opposed, were positioned within the gearbox casing, and were permitted to move axially, having rigidly attached to them a cylindrical gear locking ring. Two dogs were formed on the internal face of the locking ring and could be engaged with

the dogs on the annular gear. The operating forks were in constant engagement with a selector ring, which was fitted in the gearbox over a bush, and was, therefore, free to rotate. This selector ring was formed with longitudinal lugs, which were also in permanent engagement with the slots cut in the planet carrier, which therefore rotated, but since the groove in this selector ring was also in mesh with the operating fork, it could be moved axially to engage the lugs with the dogs on the annular gear.

If high gear, that is the 1:1 ratio, was required, the two gear-change spindles were moved so that the locking ring freed the annular gear, and the selector ring locked the planet carrier to the annular gear. Thus the drive from the input shaft was transmitted directly to the output shaft.

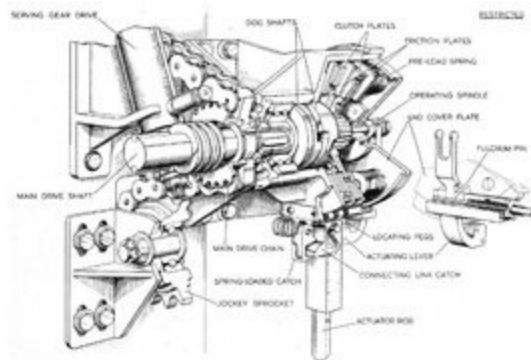
If low gear, that is the 5:1 ratio, was required, the spindles were moved so that the locking ring locked the annular gear and the selector ring moved out of engagement with the annular gear. Thus, the drive from the input shaft was transmitted to the planet carrier, which now rolled around the stationary annular gear. The planet carrier and, therefore, the output shaft would then rotate at a reduced speed.

The ends of the gear-change spindles were threaded to receive adjusting nuts grooved to accept an actuating fork. The fork was connected by a suitable linkage to an electrical linear actuator, controlled via a switch on the master operator's panel.

The output shaft of the two-speed gearbox was hollow and machined with two internal keyways to accept the main drive shaft, which had a worm gear and chain-driving sprocket positioned along its length. The worm gear drove the serving gear mechanism, and the sprocket transmitted the drive via a $\frac{3}{4}$ -inch-pitch chain to the hose drum's driving sprocket. A jockey sprocket was mounted on the drive platform and below the main drive sprocket, the bracket of

which had elongated holes in its feet that provided the necessary adjustment to maintain the correct chain tension.

The brake assembly ([Fig 114](#)) was located at the end of the main drive shaft. The shaft forming a part of the brake was secured by cast feet to the drive platform from a cylindrical cast housing, the fixing holes of which were elongated. At its outer end the casting was externally threaded to accept a cover plate, which also provided a mounting for one of the dog shafts.



[Fig. 114](#). Mk IX Hose-drum brake mechanism

The assembly comprised a dog shaft attached to the main drive shaft, a second dog shaft to which clutch plates were splined, and three friction plates alternately between the clutch plates. One dog shaft had three hardened jaws on its face, which was keyed and fitted over the end of the main drive shaft rotating within the brake's housing on a double-row ball bearing.

The second dog shaft, which was hollow, had three similar hardened dogs facing the jaws of the first dog shaft, and fitted at the opposite end into a bush, which in turn was fitted over a shaft attached by a set of screws to the cover plate. A lip at the rear end of the bush butted against a shoulder machined in the end of the second dog shaft. The forward end of the bush had a retaining cap that fitted over

the end of the shaft located in the cover plate, thus locking the dog shaft to the bush, and was spring-loaded by a light coil spring between the rear end of the bush and cover plate.

A brake-operating spindle was attached at the cover plate end of the brake assembly, and provided an attachment for the brake-actuating mechanism. Thus, in the static (stationary) condition, the second dog shaft was in engagement with the first dog shaft, and would remain in that position until the operating spindle was withdrawn by the operation of the actuator.

The outer face of the second dog shaft was splined to receive two serrated rings to which clutch plates were riveted. These steel clutch plates had bonded asbestos linings riveted to each side.

Located inside the brake housing, and positioned one either side of each clutch plate, were three friction plates slotted on their peripheries to receive the squared ends of locating pegs screwed in from outside the brake housing.

Thus, the friction plates were prevented from rotating but were allowed axial movement. Six equally spaced coil springs were inserted between the outer friction plate and the brake housing, and applied an internal loading to the clutch and friction plates so that slip could not occur at a torque of 60 pound-feet. The internal loading was preset by the position of the cover plate on the externally threaded portion of the brake housing.

From the above description it will be seen that the friction and clutch plates were always in the brake ON position, and the application of the brake to the main drive shaft was achieved by the movement of the operating spindle, which engaged the jaws of the two dog shafts.

A lug on the outer face of the cover plate housed the fulcrum for the actuating lever, one end of which engaged with the operating spindle. The fulcrum pin formed a part of

an emergency stop mechanism, and is described at a later stage. Attached to the other end of the actuating lever was a connecting link catch, which, when the brake was in the OFF position, engaged with a spring-loaded catch mounted on the outside of the brake housing. This catch mechanism was fitted between the actuator and the brake-actuating lever to ensure that when the actuator was energized for the brake ON, the brake was applied with a positive snap action, and when re-energized for the brake OFF, the brake was released slowly.

The actuator assembly ([Fig 115](#)) comprised three Rotax linear actuators mounted on a light alloy bracket bolted to the drive platform alongside the driving motor. The actuators were raised on the bracket so that their operating arms were in line with their respective components. They were all of the same type: the left-hand one operated the fluid drive coupling scoop, the centre the gear-change mechanism, and the outer one the brake assembly. Incorporated in the arm of the gearbox actuator was a spring-loaded device to prevent damage occurring to the actuator in the event of a hesitation in the gear-change mechanism.

A microswitch was mounted on a bracket above the brake actuator, the operating lever of which was positioned on the actuator's arm, so that when the brake was applied and contact was made in the microswitch, this was indicated by the illumination of a warning light on the master operator's panel.

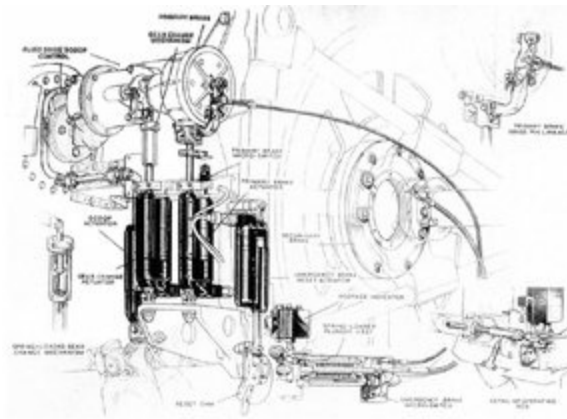


Fig. 115. Mk IX hose-drum unit actuator assembly

The Rotax actuators consisted of a DC split-field series motor driving a lead screw through a three-stage gear train, the motor being situated parallel to and below the lead screw. An internal thread cut in the ram engaged the lead screw, while limit-switches restricted the travel of the ram.

The emergency brake mechanism also shown in Fig... was incorporated in the hose-drum unit to prevent the refuelling hose from running out in the event of a power failure, which would render the normal brake inoperative. The mechanism was mounted adjacent to the main drive platform on the starboard side of the unit, and comprised a preset spring-loaded plunger in a cylindrical housing. The end of the plunger was attached to a flexible cable, the other end to the actuating lever of the brake mechanism. The spring-loaded plunger had a trip mechanism that was operated by a second flexible cable connected to the emergency stop mechanism, which is described later.

A friction-brake assembly was also attached to the inner face of the right-hand radiused retraction runner, comprising two lined blocks that bore on either side of a friction plate secured to the hose drum. The outer faces of these two blocks were wedge shaped and received two similar blocks attached to the end of the friction-brake operating lever. Thus, as the movement of the brake's

actuating lever took place, the wedge-shaped blocks were forced against the brake blocks; and the linings against the friction plate, resulting in a braking force being applied to the hose drum. The friction-brake operating lever was also fitted with another lever for manual operation during ground handling.

The serving carriage assembly was included in the design of the hose-drum unit to ensure that as the refuelling hose was either trailed or wound-in, the lay of the coils on the drum would be correct. The assembly consisted of a drive mechanism, a cam-box, and a hose guide. The drive mechanism consisted of a lay shaft carried in plain bearings fitted in a tube attached by brackets to the drive platform alongside the two-speed gearbox. At one end of the shaft was a worm wheel, which meshed with the worm gear on the main drive shaft, and at the other end a worm gear was keyed in position and secured by a nut.

The cam-box mounted across the top of the drive platform housed a centre shaft and drum; the shaft, which was mounted on a ball thrust bearing, protruded through one end of the cam-box and had a worm wheel and cam plate keyed and locked in position. The worm wheel engaged with the worm gear mentioned in the previous paragraph, and the cam plate formed a part of the emergency stop mechanism described later. The drum had a left-and-right-hand helical slot cut along its length, and was fitted over the centre shaft that was located at the end of the drive shaft by four keys secured in position by countersunk screws. A slot was cut in the box to clear a roller attached to one end of the serving gear lever, which pivoted on a ball bearing, the inner race of which fitted over a pin mounted on the reverse side of the drive platform. Thus, as the cam drum rotated, the roller, which engaged with the drum slot, moved backwards and forwards across the cam slot, and since the pivot point was approximately a quarter of the way along the lever, the movement of its lower end was accentuated

The lower end of the lever was connected by a link to the serving carriage. This carriage, or guide, was a key-holed-shaped, cranked casting bored transversely at its upper end to clear the hose-drum unit cross-frame tube at the base of the drive platform. Three equally spaced rollers were fitted at each end of the bore to ensure easy and frictionless movement of the carriage over the cross-member. The lower end of the carriage was transverse shaped so that it fitted over the lower cross-member of the frame, which had two diametrically opposed rollers fulfilling a similar function to those on the transverse bore.

The rear face of the upper portion of the serving carriage was machined flat to receive a steel, horseshoe-shaped plate, which formed an arrester plate for the metal 'slug' attached to the refuelling hose. A rubber buffer fitted around the forward face of the circular portion of the key-hole slot to minimize the shock loads imparted to the carriage when the reception coupling reached the fully stowed position. A spring-loaded plunger fitted on the right-hand side of this part of the carriage and protruding into the circular bore operated directly on a microswitch. This switch operated the HOSE-IN warning light on the master operator's panel.

In the emergency stop mechanism, the cam plate on the end of the centre shaft in the cam-box had a spiral groove machined on its outer face to engage one end of a lever mechanism. This lever was mounted on the top right-hand corner of the drive platform, and controlled an emergency stop device connected by a flexible cable to the fulcrum pin of the brake mechanism actuating lever. This cable had a junction box from which a second cable was led to the emergency brake mechanism previously described. The spiral in the cam wheel was so designed that, after a predetermined number of turns, the hose drum, the lever end when engaged was raised, thus, actuating through the lever mechanism the trigger of the emergency stop device which, when tripped, applied a brake load to the flexible

cable and partially withdrew the brake lever fulcrum pin. The withdrawal of the pin permitted the brake dogs on the dog shaft to engage, irrespective of the brake actuator position.

The stop mechanism comprised a spring-loaded pin housed in a cylindrical barrel preset and held in compression by a small trigger arm, the other end of the pin being connected to the flexible cable. The mechanism was timed to operate when approximately 2.5 turns of hose remained on the drum.

The microswitch assembly, which fitted over the hose drum bearing on the left-hand side frame, housed four microswitches: one controlled the operation of the combined fuel and vent valve in the unit's fuel system, as well as the AMBER and GREEN contact lights; another controlled the brake assembly actuator; the other two were connected in series and controlled the unit's driving motor.

The assembly also housed a threaded shaft, which was driven in an identical manner to that fitted to the Mk XI wingtip units, the microswitches being operated by a similar cam nut.

Before the hose was trailed, and when the master electrical switch was ON, the fuel valve would be opened and the vent closed, and the GREEN contact light illuminated. As the hose was trailed and the drum rotated, the cam nut moved along the threaded shaft and tripped the fuel valve microswitch when approximately 6 feet from full trail.

The operation of the switch closed the fuel valve and opened the vent, at the same time extinguishing the GREEN contact light and switching on the AMBER. As the hose was trailed beyond this point, when within 4 feet of the fully trailed position the second microswitch would be tripped. This switch energized the brake actuator and applied the brake. When the refuelling hose was wound in, the reverse of this sequence took place until approximately 3 feet of

hose remained trailed. With the refuelling hose at this position the unit's driving motor microswitches were tripped, automatically switching the driving motor OFF. To finally stow the reception coupling, and fully wind the refuelling hose onto the drum, the driving motor had to be switched to ON by depressing the MOTOR-START button on the master operator's control panel. The circuit was so arranged at this point that the MOTOR-STOP switch was inoperative, and the MOTOR-START button had to be depressed and held in position for the motor to continue running.

The control panel shown in [Fig 116](#) was that used for controlling the Mk IX rear fuselage hose-drum unit, and formed a part of the master operator's panel shown in [Fig 66](#), illustrated in the Boeing B-29 Superfortress installation.

Functioning of the Mk IX hose-drum unit, described in the following paragraphs, merely correlates the function of the various components and associated equipment previously described. It must firstly be assumed that the hose-drum unit was in the fully retracted position and the sliding door closed, with the main electrics OFF. The operating procedure was as follows:

Switch the main electrics to ON (the power failure warning light on the main supply panel will be illuminated). Check that the hydraulic selector is in the 'UP' position, and ensure that the circuit breakers on the selector panel are closed. Select 'NORMAL', which energizes the hydraulic pump with the warning light switched 'ON'. If, however, the pump fails to start, the switch has to be selected to 'ALTERNATE', which starts a second pump within the hydraulic package. The interconnection between these two pumps has been modified from their original installation; prior to the modifications when 'ALTERNATE' was selected, both pumps were operative at the same time, but now they have the capability of being operated singly. The hose-drum unit is now hydraulically stalled in the 'UP' position, and the

solenoid plungers within the up-lock towers are relieved of any load. The sliding door is now selected to 'OPEN', and the open warning light is illuminated, indicating that the door is fully open; the hydraulic selector lever is then selected to 'DOWN'. The operation of the lever instantly energizes the up-lock solenoids and withdraws the plungers. The unit is then lowered to its fullest extent. When fully down the hydraulic package can be switched 'OFF'. It is important that the unit is allowed to go right down to its limits, as the up-lock solenoids have a 90-second rating, and will otherwise remain energized until the microswitch in the cup shaped blocks is operated. Also, it is important to maintain the correct sequence of operations because of the safeguards employed within the electrical circuits.

Fig. 116. Mk IX hose-drum unit control panel



To trail the refuelling hose, the first check to be made was that the circuit breakers on the left-hand side of the master operator's panel were pressed in. 'TRAIL' could then be selected, which automatically selected 'LOW' gear within the gearbox and set a low scoop setting within the fluid drive coupling. The 'MOTOR-START' button was then depressed until the 'INITIAL-TRAIL' indicator light on the control panel was extinguished; the refuelling hose automatically commencing to trail.

When the refuelling hose showed 6 feet from full trail, the fuel valve was energized to closed and the vent to open; the GREEN contact light was extinguished, and the AMBER illuminated. On the refuelling hose reaching the full trail position, the brake was automatically applied and the FULL-TRAIL and BRAKE-ON lights were illuminated. The driving

motor was then switched to OFF and the TRAIL switch to OPERATION, the driving motor being selected to MOTOR-START. Automatically the gear-change actuator was energized, selecting 'HIGH' gear and the scoop actuator of the fluid drive coupling to the operational setting; the unit then being ready for a receiver aircraft to make a contact.

When the operation was completed and the receiver aircraft had broken contact, the driving motor was then selected to OFF, and the TRAILWIND switch changed from OPERATIONAL to WIND-IN. The gearbox actuator was again energized and changed gear from 'HIGH' to 'LOW'. The driving motor was then selected to MOTOR-START, and the refuelling hose commenced winding in against the brake ratcheting. After 6 feet had been wound in, the brake was automatically disengaged via its actuator being energized. Also, the fuel valve was closed and the vent opened, the AMBER contact light was extinguished and the GREEN illuminated.

When the refuelling hose was within 3 feet of the fully stowed position, the driving motor was automatically switched to OFF via the microswitch assembly, and the brake applied. To fully stow the hose, the MOTOR-START button had to be held depressed, and when the reception coupling was fully stowed in the serving carriage, the microswitch within the hose guide was tripped, and the HOSE-IN indicator light was illuminated, together with the BRAKE-ON light. The BRAKE-ON switch was similar to that employed on the Mk XI wingtip unit, which had a gate protection, and was for GROUND-USE, only operating in a similar manner.

Safety devices were incorporated in the Mk IX unit in the event of an electrical failure within the system. If there was a driving motor failure, the electrical circuit was so arranged that the brake was automatically applied. However, should a failure occur within the brake's actuator when the hose was being trailed, the cam plate fitted on the end of the serving

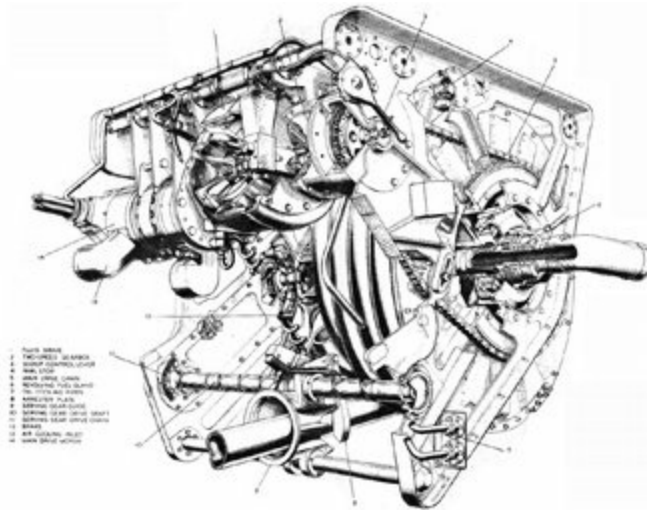
gear cam-box would operate the emergency stop mechanism when 1½ turns of hose remained on the drum, and the brake would be applied. At the same time the emergency friction brake on the hose drum would also come into operation, and prevent the drum from further rotation. In this event the EXTREME-TRAIL warning light would be illuminated, this being located on top of the fuel indicator panel. In the condition of extreme emergency, the 'slug' on the refuelling hose would butt against the arrester plate on the serving-gear carriage, thereby preventing any further hose trailing taking place.

CHAPTER THIRTEEN

Mk XI Hose-Drum Unit

The Mk XI hose-drum unit ([Fig 117](#)) was specially designed for wingtip refuelling, and was for single-seat jet fighters of the period.

Fig. 117. Mk XI wingtip hose-drum unit



The unit comprised the following major components: a prefabricated flanged drum mounted between two cast side plates, capable of storing 77 feet (23.7 metres) of 2¼-inch-bore (57 mm) refuelling hose, a main drive assembly, hose serving carriage and guide, a rotating fuel gland, brake mechanism and emergency pawl stop and reception coupling and drogue.

The main drive assembly provided the motive power for the hose-drum unit, which comprised an electric motor, a

fluid drive coupling, and two-speed gearbox.

The motor was a BTH-type LD.2715, having the characteristics of a DC compound wound motor, and was rated at 5 h.p. at 3,000 rpm, with a line voltage of 26.5 volts. The motor was air-blast cooled by air being forced onto the brush gear and commutator from the forward-facing scoop fitted to the aircraft's wing nacelle. An air outlet at the end of the motor allowed the cooling air to be freely exhausted to atmosphere. The direction of the motor's rotation was nonreversible and always rotated in the wind direction.

A reduction gear, which had a ratio of 1.66:1, was fitted between the output end of the motor and the input to the fluid drive coupling. The coupling was incorporated into the drive system to permit the motor to start up under no-load conditions and to ensure a smooth acceleration and deceleration of the hose drum due to its capability of varying the torque output.

The fluid drive coupling comprised a circular cast housing having at one end a scoop tube mounting and at the other a flange for its attachment within the drive system. Internally, and mounted on the output shaft; were an impeller and a runner, each having a row of single-sided bucket-shaped blades, both being contained within a split back and outer casing bolted together. The impellers and runners were so arranged that their blades were opposed to each other with a small clearance between them. The impeller was secured to a further inner casing, having oil-transfer ports at the scoop end of the coupling, being mounted on two bearings located in the back casing. The impeller and inner casing were therefore free to rotate independently of the runner. The scoop tube was located within a housing machined off-centre in the circular housing, and was connected by a lever and flexible cable to a control box on the right-hand side plate of the hose-drum unit. The cable was spring loaded, so that in the event of a cable failure the scoop setting

automatically went to the MAXIMUM position. A tundish was mounted on the scoop tube housing to permit the filling of the coupling with the necessary oil.

Oil inlet and outlet pipes were connected to the circular housing of the coupling, and were routed to a bracket mounted at the bottom of the hose drum's right-hand side plate, and thence to the oil cooler located in the nose of the wingtip nacelle.

When the input shaft of the coupling that was secured to the back casing was rotated, the oil in the casing was whirled around the casing's longitudinal vanes and forced up the scoop tube. The oil was then fed between the impeller and runner blades, imparting a drag on the runner, thus revolving the output shaft. Because of the friction generated, the oil became hot and was bled away to the oil cooler, which received the ram-air from its position in the wing nacelle. After cooling, the oil was returned to the casing. The amount of torque being transferred from the coupling was varied by the raising or lowering of the scoop tube and thus the volume of oil.

The output shaft of the coupling was connected to the input side of a two-speed gearbox, the ratios of which were 4:1 and 14:1 respectively, and a 23-toothed chain sprocket was attached to the gearbox output shaft, providing the final drive via a $\frac{5}{8}$ -inch-pitch chain to the hose drum's drive sprocket. Control of the gear change was by a Rotax rotary actuator operated by a switch on the operator's control panel.

The gearbox comprised a cylindrical housing and an epicyclic train of gears, having two sets of planetary gears and an internally toothed annular gear, as shown in [Fig 118](#). The input shaft had a gear machined integrally with the shaft at approximately its mid-position, and was splined at either end; one received the fluid drive coupling's attachment, and the other a spur gear. The two sets of

planetary gears were identical, having four gears, each mounted within cages. The drive was transmitted to them by two spur or sun gears on the input shaft. The cage of the outer planetary gears, which derived their drive from the sun gear at the end of the input shaft, carried the output driving sprocket, whereas the cage of the inner set of planetary had a toothed flange on its outer periphery that was identical to, and adjacent to, a toothed flange on one end of the annular gear. The internally toothed annular gear, which was mounted in the gearbox housing, was of sufficient width to mesh with both sets of planetary gears. The gear-change mechanism was at the top of the gearbox between the two mounting flanges.

If the high-gear 4:1 ratio was required, the gear-change mechanism locked the annular gear by the insertion of a spring-loaded plunger into the toothed flange. When the input shaft was rotated, both sun gears of the shafts were also rotated, as were the planetary gears and their cages. The inner cage, while being free to rotate, was not at this stage driving any part of the gearbox. The other cage, however, was connected to the output sprocket, thus a reduction of 4:1 was effected between the input and output shaft. If the low-gear 14:1 ratio was required; the gear-change mechanism unlocked the annular gear, leaving it free to rotate, but locked the toothed flange that formed a part of the inner planetary gear cage. When the input shaft was rotated, both sets of planetary gear would also rotate, but only the output cage was free to rotate, because the inner cage was fixed; any rotation of the planetary gear would rotate the annular gear. Since the outer set of planetary gears was also being rotated against the moving annular gear, a greater reduction would be effected on the output cage.

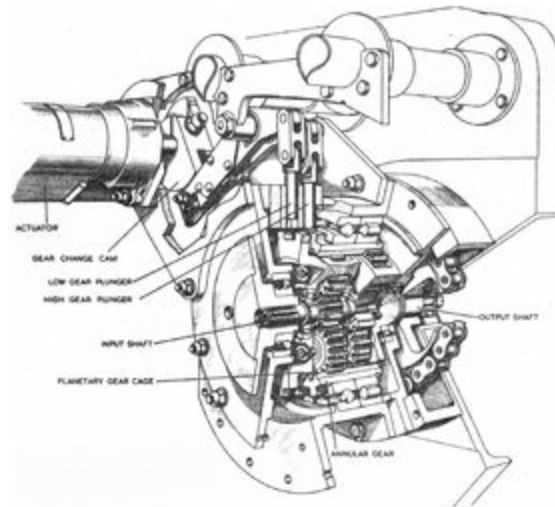


Fig. 118. Mk XI hose-drum unit two-speed gearbox

The gear-change mechanism consisted of a Rotax electrical rotary actuator limited to 180 degrees of travel. The actuator was connected to a drive plate to which were attached two spring-loaded plungers. These were arranged in a housing on top of the gearbox, and were so positioned that when one plunger was in mesh with the toothed flange of the annular gear, the other was clear of the flange on the inner cage. They were spring loaded to permit a change of gear when opposite a tooth. In this condition the actuator could travel its full movement, the plunger automatically being forced into position as the movement of the gears took place.

A serving gear and guide was incorporated on the hose-drum unit to ensure that as the refuelling hose was wound in, the lay of the coils on the drum would be correctly formed. The serving gear assembly comprised a stainless steel shaft having an Archimedean thread along it, a slide tube and the hose guide.

The Archimedean shaft was fitted between the side plate of the hose-drum unit at the rear and to the bottom of the plates. The shaft was located on bearings within machined housings bolted to the side plates. The left-hand end of the

shaft protruded through the side plate to accept a chain sprocket that meshed with a chain-drive sprocket secured to the hose drum, the ratio between the two being 1:1.

Below and parallel to the Archimedean shaft was a tubular slide member upon which the lower portion of the hose guide slid when being driven by the hose drum. The hose guide was a hollow cylindrical casting that had a belled flare at its rear end, the lower portion having two lugs, each machined to accept a bronze bearing, the internal diameter of which allowed a sliding fit over the tubular member. At the top of the guide two further lugs had bearings similar to those at the bottom, which slid over the Archimedean shaft. Between the two lugs, and mounted vertically, was a driving pin, the shaft of which was supported by two ball bearings. The pin was elliptical in shape and was positioned so that when the hose guide was fitted it engaged the Archimedean thread. Thus, when the hose drum, and therefore the Archimedean shaft, was rotated from left to right and back again, as the hose was fed through it was correctly coiled on the hose drum in two layers. However, the guide lagged behind the lay of the hose by approximately $\frac{1}{2}$ inch, which ensured that the hose coils lay close to each other.

Fitted to the upper face of the hose guide was a bracket to which an arrester plate was hinged. The plate was horseshoe shaped, and fitted over the refuelling hose to provide an emergency stop for a metal slug attached to the hose. It was retained in the vertical position by a length of rubber cord, which allowed the plate to swing and the reception coupling's hose adaptor to slide home. A microswitch was also mounted on top of the hose guide, being operated by a plunger that protruded through a hole in the rear of the guide. The microswitch was connected to the BRAKE-ON warning light on the operator's control panel, and was illuminated when the reception coupling entered the guide to the stowed position. This did not mean, however, that the hose-drum brake had been applied unless the hose-drum

driving motor had been switched OFF, but indicated that the coupling was in the stowed position.

The brake pawl mechanism, automatically operated, was fitted to limit the length of refuelling hose that could be trailed from the tanker. The mechanism comprised a rotatable tubular cross-member on which two pawls were mounted. The cross-member was located across the top of the hose drum forward of the drive system, and rotated within bearings housed in each side plate. The pawls were so positioned that they engaged with slots in the hose drum's side flanges and prevented any further rotation of the drum in the trailing sequence. A lever that was positioned on the tubular cross-member, and between the two pawls, was attached at its upper end to two return springs, so that under static conditions the pawls were engaged on the hose drum's flanges but clear of the engaging slots. The lower end of the lever was slotted and received a guide block and securing pin for the operating lever of an electrical linear actuator. The actuator was mounted on the drive system above the motor's spur gear. The actuator, when energized, pulled against the pawl return springs, and retracted the pawls from the drum flanges. When approximately three turns of refuelling hose were left on the drum, the actuator was automatically de-energized via a microswitch mechanism that allowed the return springs to snap the pawls against the drum flanges or into the engaging slots. The actuator arm contained a spring relief mechanism to prevent damage occurring in the event of a rapid pawl engagement.

An emergency mechanism was also included in case the actuator failed, and left the pawl stops out of engagement. The mechanism was attached to a microswitch assembly, which was controlled by the number of turns of the refuelling hose remaining on the drum. In the event of an actuator failure it would withdraw the pin securing the actuator to the pawl lever, and would thus cause the return springs to snap the pawls into engagement.

The microswitch assembly shown in [Fig 119](#) controlled the operation of the pawl stop actuator, the fuel and vent valves applicable to the wingtip unit. It also operated the two indicator lights, GREEN and AMBER, fitted to the underside of the tail fairing of the wing nacelle, and were interconnected electrically with the pawl stop microswitch.

The microswitch assembly was mounted on the left-hand side plate of the hose-drum unit, and fitted over the hose serving guide chain-drive sprocket, the latter being keyed to the hose-drum shaft. The assembly comprised a circular machined housing containing a threaded shaft and cam, two microswitches and the mechanism for operating the emergency pawl stop.

The end of the hose-drum shaft was slotted to receive one end of a universal coupling, the other end of which engaged with the threaded shaft that rotated in two ball bearings fitted within the assembly's machined housing. Thus, as the hose drum rotated, the drive was transmitted to the threaded shaft, driving the cam along the thread. To prevent the cam from rotating, it had a longitudinal slot machined in it that engaged with a spring-loaded adjusting plunger. The two microswitches were mounted on the outer side of the machined housing, one above and below the threaded shaft, both having their trip arms facing inwards towards the cam. As the cam travelled along the threaded shaft it automatically switched the microswitches in the correct sequence. The upper switch controlled the wing unit's fuel and vent valves, and the lower the pawl stop actuator.

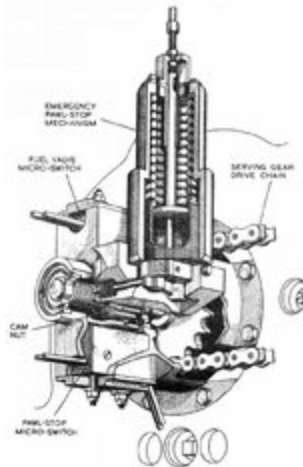


Fig. 119. Mk XI hose-drum unit, microswitch assembly

When the refuelling hose had been stowed, the master switch on the control panel was switched to ON, the wing fuel valve was OPENED and the vent CLOSED, the GREEN indicator light illuminated. As the refuelling hose was trailed and the hose drum rotated, the cam moved along the threaded shaft and tripped the fuel and vent valves when the hose was within 4 to 6 feet of being fully trailed. The operation of this switch closed the fuel valve and opened the vent, also extinguishing the GREEN indicator light, together with applying the hose drum's brake and illuminating the BRAKE-ON light on the control panel. As the hose was trailed beyond this point, by selecting OPERATION on the control panel the brake was released and the AMBER indicator light illuminated. The second microswitch was then tripped, which operated the pawl stop actuator, and the return springs snapped the pawls into engagement.

When it was required to wind in the refuelling hose, the hose drum driving motor had to be stopped for the gear-change operation. A pause of 15 seconds was needed to permit the gears to come to rest, and WIND-IN then had to be selected on the control panel. The motor START button was then pressed and the refuelling hose would begin to wind in, the indicator lights (it was at about this time that

the terminology of the indicator lights was changed to CONTACT LIGHTS, a really more logical term that the reader will find is now used) would automatically go to GREEN and the brake warning light would be illuminated once the refuelling hose and coupling were fully stowed.

The emergency pawl stop mechanism, also shown in [Fig. 119](#), was fitted to one side of the microswitch assembly, and only came into operation if there was a failure of the normal actuated system. The mechanism comprised a spring-loaded dashpot having an internal plunger attached to an external flexible cable, the plunger being held in the loaded position by a trigger lever. This lever was tripped by an operating pin located in the side of the assembly. The pin only came into action when 1½ turns of refuelling hose remained on the drum during a trailing sequence, and the cam had actuated the pawl stop microswitch that had failed to engage the pawl stops into the hose drum slots.

When the emergency pawl stop mechanism had been operated, it was still possible for the hose to be wound back onto the hose drum. But it was impossible to retrail it because of the need to reset the dashpot when the aircraft was on the ground. The operation was indicated to the master operator by a warning light on a small panel above the master operator's main control panel.

The main hose-drum brake was one of the two leading shoe types, 9 inches x 1¾ inches overall, and mounted on the left-hand side of the hose drum between the drum and side plate. A brake operating lever protruded through the side plate, one end of which was attached to a bell-crank lever, the fulcrum point also being attached to the side plate. The other end of the bell-crank was attached to the forked end of a spring-box assembly to prevent the overloading of the brake electrical actuator. The spring box comprised a cylindrical machined housing, an adjustable cylinder cap and a compression spring-loaded plunger; the cylinder cap providing the necessary adjustment for the load that had to

be applied.

Indication of whether the hose-drum brake was ON or OFF was by a warning light on the operator's control panel, actuated by a microswitch attached to the left-hand side plate and adjacent to the spring-box plunger. The plunger was also adjustable to ensure that its travel matched that of the actuator; it operated the microswitch by an attached plate.

The refuelling hose shown in [Fig 120](#) was a 77-foot length of 2¼-inch bore, rubber lined, with a woven cotton outer cover, and was reinforced by a steel helical wire. One end of the hose was secured on the right-hand side of the drum to a rotating seal, the other to the reception coupling.

At a point approximately 2 feet from where the hose entered the drum, a metal sleeve, or slug, was fitted as an additional emergency device to prevent the hose trailing out to its fullest extent, thereby avoiding the danger of it shearing at the drum face. In an emergency the slug butted against the arrester plate fitted to the serving gear hose guide. At 10-foot intervals along the hose from the reception coupling end, black bands were painted on the woven-cotton cover to indicate to the receiver pilot the length of hose trailed; similarly red and white bands, at very close intervals at the hose drum end, indicated when the maximum hose length had been trailed.

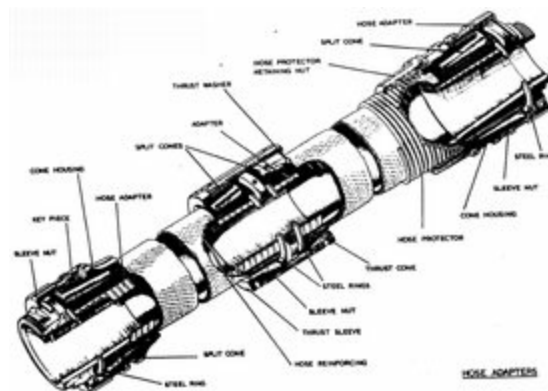


Fig. 120. Mk XI hose-drum unit refuelling hose

To connect the hose to the reception coupling, and to the hose drum, together with the emergency slug, special adaptors were required capable of withstanding the high-tension loads applied to the hose when a receiver broke contact. The adaptors were fitted at each end of the hose with the slug approximately 45 inches (1,144 mm) from the drum connection. The adaptors consisted of the following principal items:

1. A steel ring, split cone and cone housing.
2. A hose protector, retaining nut and snap ring.
3. A hose adaptor, thrust ring, sleeve nut and locking key.

To assemble the adaptor to the reception coupling, a short length of the hose was bared of its cotton cover, the internal longitudinal strands being turned back over the steel ring, the hose protector and retaining nut, the cone housing having been slid over the outer cover. The hose adaptor was a thin-walled cylinder having an external shoulder positioned approximately one quarter along its length, one end being externally threaded, the other serrated. The serrated portion of the adaptor was inserted into the bore of the hose until the shoulder abutted the strand-covered ring. The helical reinforcing wire was drawn into a small hole in the adaptor's shoulder and locked by a grub screw, thereby ensuring a good electrical continuity. The split cone was then positioned over the exposed longitudinal strands and retained by the cone housing. The thrust ring was located on the hose adaptor at the threaded end and retained by the sleeve nut screwed to the cone housing.

The adaptor connecting the refuelling hose to the drum was similar to that of the reception coupling's adaptor, except for the hose protector and retaining nut. Likewise, the slug's adaptor was similar in assembly to the other adaptors, but had two ends of hose adaptor serrated, and

had thrust cones fitted at the reception coupling's side.

The reception coupling and drogue ([Fig 121](#)), were similar to the three hose-drum units, the wingtips being identical. However, the rear fuselage unit, while being similar, was slightly modified internally at the ball joint, having a larger bore to achieve the higher fuel flow rates.

This design of reception coupling and drogue was similar to that used in the initial wet trials of the new refuelling system, which was developed to include night lighting for night operations. Three small lamps were fitted at equal intervals within the drogue's interior, the power for the lights being supplied by three batteries attached to the coupling's body. They were rechargeable when ground serviced. An ON/OFF switch for ground use was also attached to the outside of the drogue, which was also interconnected through two microswitches to the batteries. It was therefore necessary to select the switch to ON prior to any night flying. However, to save the battery's power from being drained during the tanker's flight to a rendezvous, the two microswitches were operated via two spring-loaded plungers attached to the forward end of the reception coupling through its flange. When the coupling entered the serving gear hose guide, the microswitches were in the 'broken' condition (no power supplied to the lamps); both switches were wired in circuit to the ground night-lighting switch, which when set to ON made the microswitches 'live'. As the reception coupling was trailed away from the serving-gear hose guide, the drogue night lighting was automatically switched to ON.

The functioning of Mk XI wingtip control in the following paragraphs merely correlates the function of various hose-drum unit components.

It must first be assumed that the refuelling hose was in the fully stowed position with the main electrical supplies switched 'OFF'. When switched to 'ON' at the master operator's control panel, the 'POWER FAILURE' warning light and the 'BRAKE-ON' lights were illuminated. To trail the refuelling hose, 'TRAIL' was selected on the Mk XI control panel, which energized the pawl stops actuator, withdrawing them from engagement; the 'MOTOR-START' button was then depressed, and the 'POWER-FAILURE' warning light was extinguished, the hose-drum brake actuator also energized, releasing the brake, and the hose automatically trailed out.

During the time the refuelling hose was being trailed it was necessary to control the speed of the trailing sequence. This was achieved by operating the 'BRAKE-ON' switch, which was spring loaded and had to be held in the 'ON' position. When the refuelling hose was within 6 feet of being fully trailed, the fuel-valve microswitch 'CLOSED' the fuel valve and 'OPENED' the vent valve. This operation switched the 'GREEN' contact light 'OFF' and applied the hose-drum brake by energizing its actuator; the 'BRAKE-ON' light being illuminated. With the refuelling hose at this position both contact lights were extinguished. The refuelling hose was then trailed beyond this point by altering the control switch from 'TRAIL' to 'OPERATION' when the brake was released, the 'BRAKE-ON' warning light being extinguished, with the refuelling hose trailing to its fullest extent when the 'AMBER' contact light was illuminated. At the same time the pawl stops' actuator was energized, these snapping into engagement via their return springs, the 'FULL TRAIL' warning being illuminated. The wingtip unit was now ready for a contact to be made.

When made the receiver moved forward over the three

feet, to 'OPEN' the fuel valve and close the vent, the slack refuelling hose being taken up and automatically wound onto the hose drum, thereby illuminating the 'GREEN' contact light and extinguishing the 'AMBER', the former light indicating that the fuel transfer was about to commence.

At the conclusion of the fuel transfer the receiver withdrew, making a disconnect from the reception coupling at the fully trailed position. This automatically extinguished the 'GREEN' contact light and illuminated the 'AMBER'; a second contact could be made if necessary by another aircraft.

To rewind the refuelling hose it was essential to switch 'OFF' the hose drum's driving motor and to wait for 15 seconds. This pause was important before a gear change was made, owing to the gears within the gearbox being stationary prior to any selection. By selecting the control switch from 'OPERATION' to 'WIND-IN', the gearbox actuator was energized, thus changing the gears from 'High' to 'Low', the brake and pawl-stop actuators also being energized and disengaging the brake and pawl stops. The refuelling hose then began to wind in. After it had been wound in three feet the fuel and vent valves were operated, 'CLOSING' the fuel and 'OPENING' the vent; the 'AMBER' contact light was also extinguished and the 'GREEN' illuminated. The refuelling hose continued to wind in until the reception coupling reached the hose guide block on the serving carriage where the hose-in microswitch in the guide was operated. This energized the brake and pawl-stop actuators, causing the pawls to engage; the 'BRAKE-ON' warning light was illuminated, indicating that the hose was fully stowed. Finally the hose-drum motor was selected to 'OFF'. However, prior to switching 'OFF' the main electrical power, the hose-drum control switch had to be left at the 'WIND-IN' position to ensure the correct sequence of operations when the refuelling hose was retrailed.

The hose-drum brake switch was a three-positioned spring-

loaded type: in the 'up' position it signalled the hose-drum brake to be applied; in the 'centre' it signalled brake 'OFF'; the third lower position was for ground use only and was protected by a gate, making the selection a deliberate action. During the ground use of this switch the microswitch assembly would override it, thus preventing the emergency mechanism applying the pawl stops.

Two important safety features were incorporated in the control system of the wingtip units. The first was that in the case of a pawl stop's actuator failing to engage the stops at the 'FULL-TRAIL' position, either from mechanical or electrical failure, the refuelling hose continued to trail until 1½ coils remained on the drum. And at this point the pawl stop emergency mechanism was actuated via the microswitch assembly cam nut, which engaged the stops through triggering the dashpot, and illuminated the 'EXTREME-TRAIL' warning light on the master operator's control panel.

CHAPTER FOURTEEN

Mk XIV Hose-Drum Unit

In 1951, further development of the Mk IX hose-drum unit that was originally designed for the Boeing B-29 three-point tanker was commenced, and was to be for experimental purposes. This new unit was given the designation of the Mk XIV, the main feature of which was to ensure a higher fuel transfer flow rate of 300 imperial gallons (1,350 litres) per minute, intended for large bomber and transport aircraft, also reducing the time these types of aircraft had to remain in contact.

To achieve this improvement it was necessary to increase not only the bore of the refuelling hose but also its length, the latter facilitating the location of the unit virtually at any position within the fuselage. These two features required a larger hose drum to accommodate the new refuelling hose, a change to the drive gear ratio and controlling the working oil temperature of the fluid drive coupling. Minor changes were also to be included to provide improved operational indications.

The description of the Mk XIV hose-drum unit ([Fig 123](#)) only describes the modifications to bring about its improvement, as its basic structure, drive system and control were similar to that of the Mk IX. The basic hose-drum unit structure was similar to the Mk IX, though slightly wider to accommodate the larger hose drum.

The drum ([Fig 124](#)) was likewise a casting, but the basic diameter was increased from 21 to 24 inches, though the side flanges were virtually unaltered. However, the width

was increased from 13¼ to 21 inches, to accept the larger bore and lengthened refuelling hose. A new type of rotating fuel joint was incorporated in the right-hand side of the unit, which was now of a Flexibox Ltd design, connected to the internal metal fuel pipe.

Fig. 123. Mk XIV hose-drum unit

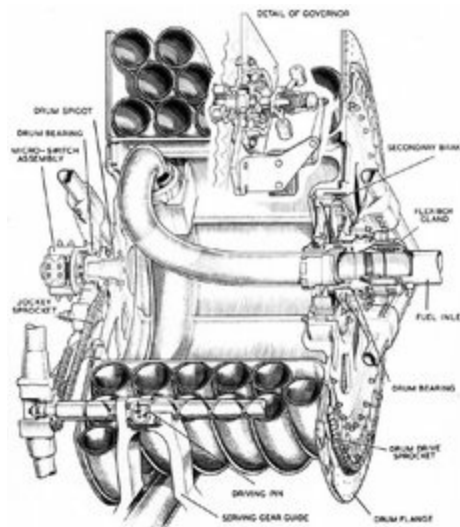
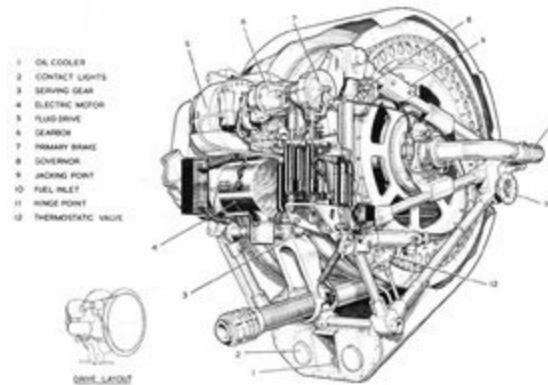


Fig. 124. Mk XIV hose drum

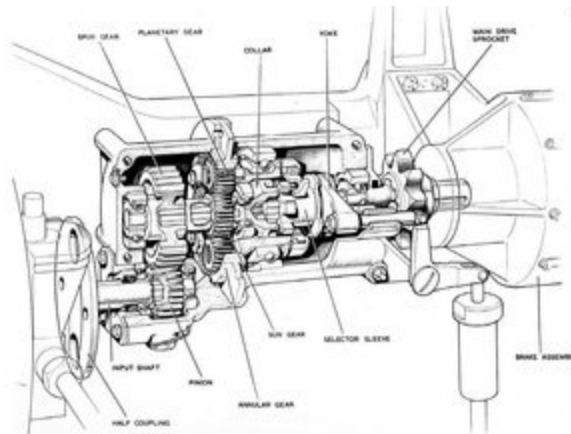
The drive system retained the Jack and Heinz 9.50 h.p. drive motor, but the drive from it was transmitted to the fluid drive coupling through a duplex chain enclosed in an oil-

tight casing. The motor had a 22-toothed sprocket, and the coupling a 37-toothed sprocket. The casing provided an oil-level filter, together with a drain plug.

Although the fluid drive coupling was of the same type, a thermostatic valve was incorporated within the oil system for the coupling. This valve automatically controlled the oil temperature to the recommended 70°C, and was located in the output pipe of the coupling to the oil cooler and teed into the return pipe. Thus, if the oil had not achieved the working temperature, it bypassed the cooler, returning to the coupling.

The two-speed gearbox ([Fig 118](#)) was replaced with a new ratio version that provided a high ratio of 1:1.68 and a low of 1:6.15.

If high gear was required, the selector sleeve was moved so that it engaged with slots in the end of the sun gear shaft. Thus, the drive from the gearbox input shaft was transmitted through the pinion and spur gear to the sun shaft, and thence to the output. This new item is shown in [Fig 125](#).



[Fig. 125](#). Mk XIV hose-drum unit gearbox

If low gear was required, the selector sleeve moved out of engagement with the sun shaft and engaged the planet

carrier. Thus, the drive from the gearbox input shaft was transmitted through the pinion and spur gear to the sun and planetary gears; the latter would roll around the stationary annular gear, this being transmitted to the output.

The brake assembly was the same as employed on the Mk IX hose-drum unit. However, a speed-control governor was introduced on this unit to prevent the refuelling hose from trailing at excessive speeds, and was preset so that the trail speed did not exceed 5 feet per second. If such a speed was reached the brake was automatically applied. It was of orthodox design and operated on the counter-weight principle. The weight, when extended, moved a spring-loaded cylinder against a microswitch which was connected electrically to the brake actuator. The governor incorporated a ratchet mechanism that would only allow it to operate during the trailing sequence. It was secured to a mounting plate, which in turn was attached to the starboard side frame, the drive being transmitted to the governor by a small pin wheel that meshed with the hose drum's main drive sprocket.

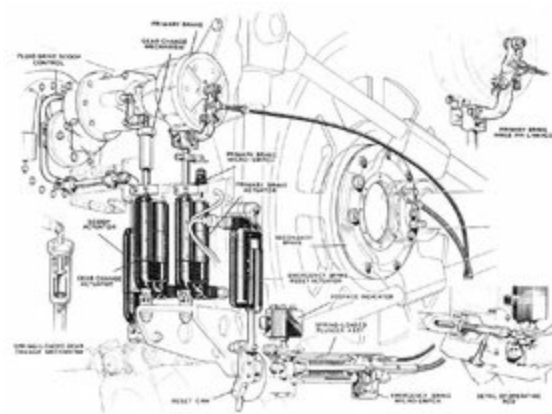


Fig. 126. Mk XIV hose-drum unit, emergency brake

The ratio between the sprocket and pin wheel was such that at a trailing speed of 5 feet per second it represented a governor speed of 1,200 rpm.

The emergency brake on this unit no longer employed the large braking disc and brake blocks, as on the Mk IX hose-drum unit, but instead a standard-type Girling running shoe brake was incorporated in the starboard hub of the hose drum ([Fig 126](#))

This braking system was brought into operation only in the event of the hose being trailed beyond the normal FULL-TRAIL position, or in the case of an electrical failure of the brake actuator, and if there was a delay in the application of the main braking system.

The mechanism to operate the emergency brake is also shown in [Fig 126](#), comprising a spring-loaded dashpot, an electrical linear actuator for resetting purposes. The dashpot consisted of a spring-loaded plunger enclosed in a cylindrical housing, to which were mounted a trigger mechanism and a microswitch, the latter providing an indication of the emergency brake being applied via an indicator light on the operator's panel. The plunger of the dashpot had attached to it at one end two flexible cables, one being connected to the hinge pin of the operating lever for the main brake, the other to the Girling brake within the drum hub. At the other end the plunger had a roller external to the housing, the roller engaging with a cam operated by the linear actuator when the brake required resetting.

The emergency mechanism was also fitted with a manual override, comprising a trip gear and three-positioned electrical switch, the latter marked ON, OFF and DWELL for ground servicing purposes. It was utilized particularly when the refuelling hose was being wound in under power after a ground inspection.

A further improvement was to indicate to the operator the length of refuelling hose that had been trailed. This was achieved by the introduction of an electrical footage indicator transmitter, as shown in the emergency brake ([Fig. 126](#)), this was located on the starboard side frame at the end

of the serving gear shaft.

The end of the serving gear shaft was internally threaded to accept a threaded operating rod, the rod being externally threaded along half of its length and having four longitudinal slots equally spaced along the remainder. The tip of a spring-loaded plunger mounted on the rear centre cast end fitting of the side frame fitted into one of the slots. The right-hand end of the rod, which extended through the end fitting, was machined with an annular groove, into which a small lever pinned to the shaft of the footage transmitter indicator was located. Thus, as the serving gear shaft rotated, the operating rod had a linear movement, and in turn imparted an angular movement to the lever, and hence rotated the transmitter's shaft. By this movement electrical signals were sent to the operator's indicator informing him of the length of refuelling hose trailed. The operating rod also, when fully extended, tripped the dashpot of the emergency brake mechanism.

The refuelling hose assembly was similar to that used on the Mk IX hose-drum unit, and of the same construction, but was 130 feet in length, thereby permitting the unit to be positioned virtually at any station of the aircraft's fuselage.

The unit was completely cowled in to protect the components from exposure under low-temperature conditions, as shown below, where the unit is shown on its servicing trolley.



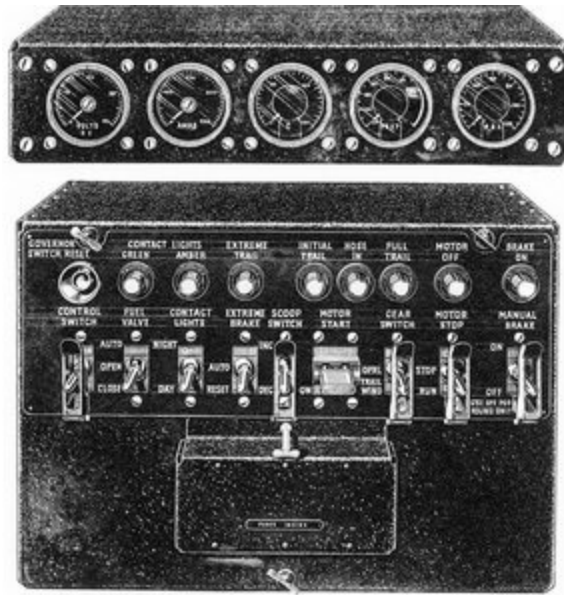
Mk XIV hose-drum unit, cowlings

The cowlings were divided into six sections to facilitate their easy removal, providing access for servicing. The Mk 3 reception coupling was incorporated on this unit, the only alteration between it and those previously employed being the introduction of an adjustable flat-faced fuel-check valve.

The Mk XIV hose-drum unit, although originally designed to develop and improve the performance, was also conceived for installation in future tanker aircraft, the conversions of which would be undertaken by the aircraft's parent company. It was therefore necessary to provide the associated items of equipment for its operation and control, together with the ground servicing instructions and electrical wiring diagrams. Also, recommendations of the components required for the fuel transfer as additional controls would be required, not only for the fuel pumping, but for the hose-drum unit's retraction system.

The following paragraphs describe the associated equipment, operating instructions and the electrical wiring between the various components.

The Operator's control panel and instrument panel were supplied with the hose-drum unit assembly, and were to be located by the parent aircraft company in a convenient position in the tanker aircraft. The control panel measured 14½ x 10 x 4 inches deep, and contained all the switchgear necessary to control the hose-drum unit, but I do not consider it necessary to describe the panel's layout in this paragraph; it is covered in the operating instructions. However, the installation of the panel was simple, it being secured to the aircraft by three Dzus fasteners, one in each corner at the top and one positioned centrally on the lower half



Mk XIV hose-drum unit, control and instrument panels

The instrument panel measured 14½ x 3 x 4 inches deep, and was to be located adjacent to the operator's panel. It contained the following instruments: a 0–40 V voltmeter, a 0–400 A ammeter, a 0–150°C temperature gauge, a footage indicator and a 0–120 psi pressure gauge. The ammeter and voltmeter were tapped into the electrical circuit (see [Fig 127](#)) so that readings were taken from the motor terminals. The temperature gauge measured the temperature of the oil within the fluid drive coupling via a temperature pocket being inserted in the return line of the fluid drive between the thermostatic control bypass line. The thermostatic valve, which was manufactured by United Aircraft Products Inc., was fitted in the output side of the fluid coupling and was set so that, should the temperature of the oil fall below 45°C, the valve allowed the oil to bypass the cooler and be returned direct to the fluid coupling.

The footage indicator was of the ratiometer type, operated in conjunction with the footage transmitter mounted at the end of the serving gear shaft.

The fuel pressure gauge recorded the fuel pressure at the

inlet to the rotating fuel joint, a tapping to accept it being made in the main fuel supply pipe outboard of the joint.

The electrical circuit for the Mk XIV hose-drum unit is shown in [Fig 127](#).

The descriptions in the following paragraphs were the operating instructions supplied with the Mk XIV hose-drum unit. It was also recommended that all operators of the equipment read these to ensure that efficient handling of the equipment was achieved by the use of the correct drill.

The instructions were given in a tabular form, with the operator's action in the first column, and the corresponding function of the unit in the second.

Reference was also made to the fuel pumping and retraction of the unit, which were the responsibility of the parent aircraft company but were not included as the systems could vary in the different installations.

The instructions assumed that the normal functional and electrical checks had been made on the equipment prior to an operation being carried out. A list of safety devices was included to correlate the operator's action with the equipment in the event of any emergency, and information was given where applicable on the method of resetting these devices.

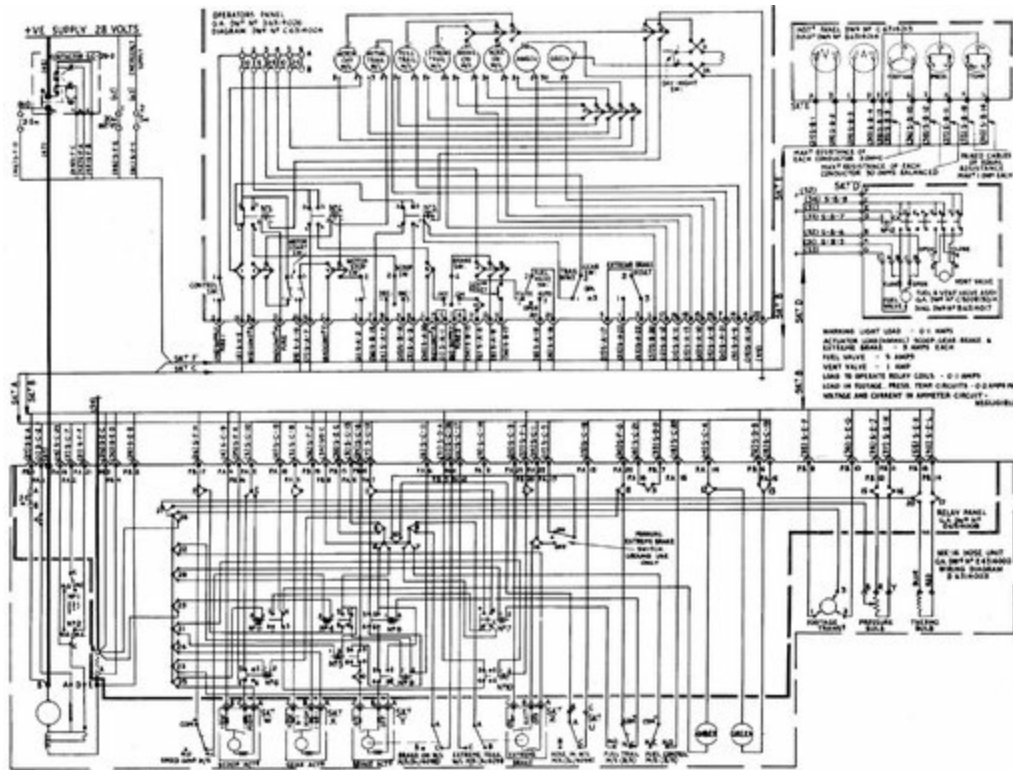


Fig. 127. Mk XIV hose-drum unit, electrical circuit

Preflight check

The following preflight check had to be made:

1. Prior to commencement of the operation the switches on the control panel have be set

CONTROL SWITCH	OFF
FUEL VALVE	CLOSED

CONTACT LIGHTS at whichever setting is applicable (NIGHT/DAY) The lighting of these, either GREEN or AMBER, indicates that the light of the same colour on the unit is also illuminated on the panel.

x EXTREME (emergency) BRAKE.	AUTO
x SCOOP SWITCH	At neutral position (mid- position)
x MOTOR START SWITCH	OFF
GEAR SWITCH	TRAIL/WIND
MOTOR STOP SWITCH	STOP
x MANUAL BRAKE SWITCH	At neutral position (mid- position)

NOTE. The switches marked with an x are spring-loaded to these positions. The Panel is now preset and ready to commence the operation.

2. Depress CONTROL SWITCH to ON	MOTOR OFF light ON
	BRAKE ON light ON
	HOSE IN light ON

With the switches set as in 1, and with the control switch ON, low gear is engaged, the fuel valve is OPEN, and the fluid drive scoop is set to MAXIMUM.

3. Depress MOTOR STOP to RUN

4. Depress MOTOR
START to ON

The motor is started and the MOTOR-OFF light switched OFF. The main BRAKE is released and BRAKE ON light switched OFF. The temperature indicator on the instrument panel should read 45 Centigrade before continuing.

NOTE: The MOTOR START switch is spring-loaded and has to be held depressed until the INITIAL-TRAIL light is switched OFF.

5. Hold the SCOOP
SWITCH at DECREASE
position until the required
reading is shown on the
ammeter-this reading is
determined by the aircraft
speed.

When approximately 6 feet of refuelling hose is trailed, the initial trail microswitches are tripped and the initial trail indicator light is switched OFF.

6. When the INITIAL
TRAIL light is switched
OFF release the MOTOR
START switch.

When the refuelling hose has trailed to within 4-6 feet from the FULL-TRAIL position, the fuel valve microswitch is tripped. The hose continues to trail until the FULL-TRAIL position is reached. At this position the FULL-TRAIL microswitch is tripped and the brake

applied. The BRAKE-ON light is switched ON. The FULL-TRAIL light is switched ON.

7. When the FULL-TRAIL light is ON switch MOTOR- STOP switch to STOP

The motor is stopped to allow the gear to be changed

under no-load condition, and the fluid drive is reset to maximum scoop. MOTOR-OFF light is ON, and FULL-TRAIL light switched OFF

8. Move the fuel valve switch to

AUTO.

The fuel valve remains closed and the vent valve open.

OPERATIONAL

(preparing the unit for a contact)

9. After a pause of at least 10 seconds select OPERATION on the gear

switch. The pause is important

High gear selected.

10. Switch MOTOR-START to RUN.

11. Depress the MOTOR-START switch and release

The motor is restarted. The

when the MOTOR-OFF light is switched OFF.

AMBER and FULL-TRAIL lights are ON. The MOTOR-OFF light is switched OFF. The brake actuator will not be re-energized to release the brake until the refuelling hose has been wound in a few feet. The brake will, however, allow the hose to be wound in since it will ratchet in wind. Immediately the brake is released, the BRAKE-ON light will be switched OFF.

12. Hold SCOOP-CONTROL switch to DECREASE until the required ammeter reading is obtained. This figure will be determined by the refuelling speed.

The hose-drum unit is now ready for a contact, and the sequence follows the same as for earlier units.

To wind in the refuelling hose

13. Switch MOTOR-STOP to STOP.

The motor is switched OFF to allow the gear to be changed under no-load conditions, and the scoop reset to MAXIMUM.

14. After a pause of 10 seconds, select WIND-

TRAIL (the pause being important).

15. Depress the MOTOR-STOP switch to RUN.

16. Depress MOTOR-START and release. When MOTOR-OFF light is switched OFF

The motor is restarted but the brake actuator will not be re energized until the refuelling hose has been wound in a few feet. The brake will, however, allow the hose to be wound in since it will ratchet in wind. Immediately the brake is released, the BRAKE-ON light will be switched OFF. MOTOR-OFF light switched OFF. FULL-TRAIL light is ON.

17. Hold SCOOP-CONTROL to DECREASE until required ammeter setting is obtained. This is again determined by the aircraft's speed.

The refuelling hose commences to wind in, the FULL-

TRAIL and BRAKE-ON lights are switched OFF. As the hose passes the 4-6 feet from FULL-TRAIL position, the fuel valve microswitch is tripped, and closed, and the GREEN contact light is lit. The hose continues to wind in until the INITIAL-TRAIL position is reached, i.e. 4-6 feet from the reception

coupling to the serving gear. The INITIAL-TRAIL micro switches are tripped and the motor is automatically switched OFF. MOTOR-ON light OFF. BRAKE-ON light ON. INITIAL-TRAIL light is ON but after several seconds is switched OFF.

18. 'Inch in' the remainder of the hose with the MOTOR-START switch until the HOSE-IN light comes ON.

Each time the motor is switched ON the brake is released, the INITIAL-TRAIL light is ON, the BRAKE-ON light and MOTOR-OFF lights are switched OFF; and vice versa. When the refuelling hose is completely stowed, the HOSE-IN light will be lit.

19. Release MOTOR-START.

The INITIAL-TRAIL light is switched OFF.

20. Switch MOTOR-STOP to STOP.

The following lights will be lit: MOTOR-OFF. BRAKE-ON. GREEN CONTACT light HOSE-IN.

21. Move fuel valve switch to CLOSED

The fuel valve is closed and the vent open.

22. Switch OFF
CONTROL-SWITCH.

All lights switched off.

Before finally switching off the CONTROL-SWITCH it was necessary to make sure that the gear switch was in the TRAIL/WIND position. This ensured that the hose-drum unit would be ready for a hose trail to be made with the least possible delay, should it be necessary.

Although some of the safety devices on this hose-drum unit have been described in previous paragraphs, it was essential that the operator fully understood their use, and so the following paragraphs give information on their action and where applicable the method of resetting them.

1. Speed Control Governor
2. Emergency Brake Mechanism
3. Extreme Emergency Hose Stop
4. 'Dead' Man's Brake
5. Manual Brake
6. Manual Fuel Valve Switch

Speed Control Governor

This governor, which was located on the right-hand side frame, taking its drive from the main hose-drum drive sprocket, was of orthodox design, and at a preset speed operated a microswitch connected electrically to the main brake. If at any time during the trailing sequence or the refuelling operation the speed of the hose 'run-out' exceeded 5 feet per second; the governor would operate the brake, and stop further rotation of the hose drum without any further action of the operator. It was also still possible to wind the hose back onto the

hose drum.

In the event of the governor applying the brake during the actual refuelling operation, i.e. while the receiver was in or had broken contact, it was essential that the operator should wind the hose in, and press the GOVERNOR-RESET switch, and then retrail the hose. This sequence was important, since it would prevent the drogue from whipping back onto the receiver aircraft if it was still in close proximity to the tanker. The receiver pilot had to be instructed to attempt a contact ONLY when the AMBER contact light was illuminated.

Emergency Brake Mechanism

The emergency brake mechanism comprised a preset spring-loaded piston operating in a dashpot. Should the hose trail beyond the normal FULL-TRAIL position, i.e. if the main brake was applied too late, or in the event of an electrical failure, the operating rod on the right-hand end of the serving gear shaft tripped the spring-loaded plunger. Two flexible cables that were attached to one end of the plunger were secured at their other ends to the main brake mechanism and the emergency brake operating arm. Indication of this emergency would be given to the operator by the EXTREME-TRAIL and FULL-TRAIL light being illuminated. To reset the mechanism the EXTREME-BRAKE switch must be placed in the reset position after the hose had been wound in, as mentioned in a previous paragraph. The switch had to be held depressed until the AMBER contact light was switched OFF.

Extreme Emergency Hose Stop

The refuelling hose on this unit also had the 'slug', or hose stop, fitted approximately 45 inches (1,143 mm) from the hose drum when the hose was stowed, and formed an additional safety device. In an extreme emergency the slug came against the face of the serving carriage, thus preventing the hose from running out to its fullest extent. In such an emergency no further attempts at a contact could be made, the hose having to be wound back onto the hose drum.

'Dead' Man's Brake

In the event of a complete power failure, or if the CONTROL-SWITCH was inadvertently tripped to the OFF position, the main brake would automatically be applied by its actuator, since the electrical circuit was so wired that the actuator drew its power from the aircraft's emergency supply. It had to be noted that at all times while the motor was switched OFF the main brake was automatically applied.

Manual Brake Switch

A manual brake switch was located on the control panel for ground use, and for emergency conditions while airborne. This switch would override all other methods of applying the brake, but could not be used to switch the brake to OFF when the hose was

at the FULL-TRAIL position.

Manual Fuel Valve Switch

The fuel valve switch on the operator's panel had three positions: AUTO, OPEN and CLOSED. In the event of a failure of the valve in the AUTO position, it could be operated manually.

In the Mk XIVB version of the hose-drum unit there was an important warning regarding the AC motor, which was as follows: The 10 h.p. AC motor was not continuously rated in excess of 25,000 feet altitude. At altitudes above this figure it had to be operated in accordance with the 30 minute-ON, 30 minute-OFF cycle.

If it was required to revert the Mk XIVB to standard, it would be necessary to replace the AC motor with the DC motor and alter the electrical circuit accordingly; it would also be necessary to remove the extended-level filler-plug on the gearbox and chain case. It would not, however, be necessary to remove the shorter type of fuel inlet pipe, as an attachment assembly could be supplied, which, when bolted on, would take the original form as the pipe on the Mk XIV. If this conversion was carried out the unit designation would become a Mk XIVC. The only difference between Mk XIV and the Mk XIVC was that the Mk XIVC had with it a kit of components necessary to convert it to a Mk XIVB.

Two of the Mk XIV hose-drum units were built, the first being installed in Lancaster G-33-1, for development flight trials. Eventually both units were sold to America for further flight trials with the American Air Force, and were at the time in competition with the Boeing boom method of air refuelling.

One unit was installed in the Boeing B-47 0040, and the other in a Convair B-36 Stratofortress with a retractable boom through which the refuelling hose was trailed. Although the trials were successful, the Boeing boom method was accepted for operational use with the American Air Force.

The Boeing B-47 receiver aircraft employed the Mk 7 probe nozzle, to match the reception coupling on the Mk XIV hose-drum unit. It was similar to those previously described, in that it was operated by hydraulic actuation and the internal fuel valve was now a flat-faced type.

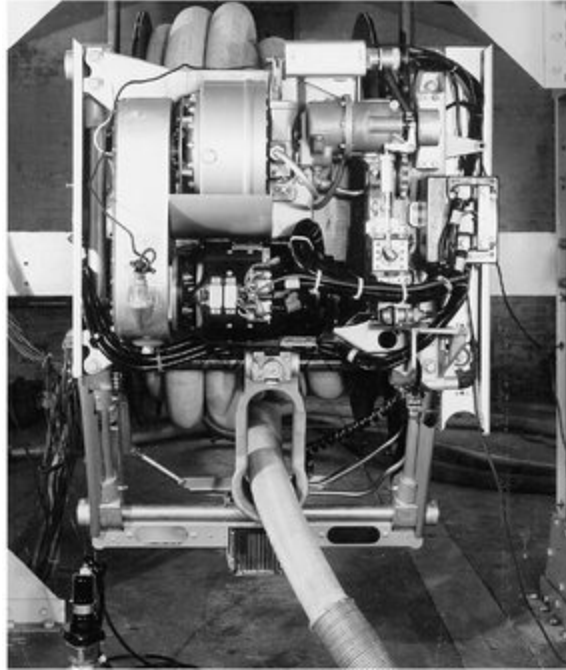
CHAPTER FIFTEEN

Mk XV Hose-Drum Unit

and Canberra B Mk 2 WH.734

The Mk XV hose drum was designed in 1952 after further experience with the American Air Force trials with the Mk XIV in the Boeing B-47 Stratojet and the B-36 Stratofortress.

It still retained retained some of the major components of the earlier Mk IX units. However, this particular design was conceived for the American Air Force, where the parent aircraft company would incorporate the necessary fuel-pumping and control system. The major redesign was the incorporation of the liquid spring method of arresting the rotation of the hose drum when the hose reached the full-trail position. The basic structure of the unit was retained in the most part (tubular framework), though on the port side a large casting was introduced to accommodate the liquid spring system. This method of braking also abolished the original two separate braking systems on the main drive of the unit, which could now be modified by the removal of the two brake actuators, and the brake attached to the drive gearbox as the new system applied the braking action directly to the hose drum.



Mk XV hose-drum unit

The liquid spring braking system, as shown in [Fig 127](#), incorporated two braking systems within one assembly. The full-trail brake could be applied automatically via a mechanical drive, and the second system was an emergency brake operated automatically or manually in the event of the hose trailing at too great a speed, or because of an electrical fault within the hose-drum unit's electrical system. The design of the system was such that it was capable of accepting the loads when the hose trailed at a maximum of 5 feet per second; and with any sudden rapid increase of speed, e.g. a hose runaway of 15 feet per second, the high shock loads could be absorbed via the liquid spring.

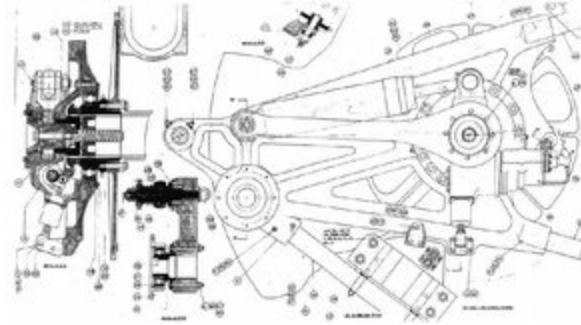


Fig. 127. Liquid spring braking system

The automatic braking when the hose reached the full-trail position was achieved by a dog nut threaded onto a lead screw externally splined, which enabled it to slide in a slide sleeve, the sleeve having fabricated rails. The dog nut was located at the free end of the lead screw when the hose was in the stowed position, and as the drum rotated, trailing the hose, a linear motion was imparted to the dog nut. The number and pitch of the lead screw were such that the dog reached the end of its travel when the hose reached its full-trail position. Its teeth then engaged with an engaging ring, so causing sufficient movement of the liquid spring operating arm and in turn applying a load to the spring.

The emergency brake was located in a dished circular cast housing secured to the centre of the port side frame of the unit. The brake mechanism consisted of an externally serrated plug, an internally serrated operating arm, engaging ring, dog ring, yoke and linkage assembly, a cam operated by an electrical rotary actuator, and a locking solenoid with a microswitch.

The flanged head of the serrated plug was located in a bush within the cast housing, and passed through the liquid spring operating arm, and thence through the engaging ring. The engaging ring was also located in a bush, thereby centralizing it and the operating arm. The exterior face of the engaging ring was also serrated to accept a spring-loaded dog ring having a toothed face that engaged with

corresponding teeth on the drum's hub. As the housing was secured to the side frame and the drum hub rotated with the drum, these teeth engaged with each other, and the drum was arrested by the operation of the liquid spring.

To release the engaged teeth, the cam-operated yoke, which pivoted within the housing, disengaged the teeth when the cam was rotated by the actuator.

When the emergency brake was ON the locking solenoid was de-energized, as shown in [Fig 127](#), and could only be released by selection of the circuit selector on the operator's control panel. This then completed the circuit to the rotary actuator, the cam rotating through 360 degrees, and imparted a lateral motion to the yoke, disengaging the dog ring. At this point, a spring-loaded plunger was forced by its return spring into the solenoid's base until a shoulder on the plunger abutted the base plate, and the pin linking the solenoid to the yoke dropped into a recess at the end of a slot in the linkage mechanism. Mounted externally on the solenoid was the microswitch, which was operated by an operating rod attached to the solenoid's plunger. As the plunger was forced through the solenoid the rod operated the microswitch, thereby energizing the solenoid that held the brake in the OFF position

The solenoid's electrical supply could be interrupted by the operation of the OFF and RESET switch on the operator's control panel, automatically by the hose-drum unit speed-control mechanism, the operation of the circuit selector switch, and by an electrical failure. In each instance the emergency brake was automatically engaged.

Owing to the introduction of the new braking system, the main drive assembly of the hose-drum unit could now be modified to a much simpler assembly, because the two brake actuators required to operate the original two braking mechanisms (main and emergency) were no longer required.

The assembly retained the drive motor, the chain case and

fluid drive coupling at the original positions, the gearbox being redesigned to incorporate the drum's driving sprocket. The fluid drive scoop actuating mechanism was moved to above the gearbox, now being operated by a rotary actuator.

The Mk XV hose-drum unit retained the same items of control equipment employed on the Mk XIV unit, i.e. overspeed governor, hose footage transmitter, the fluid drive's oil system, and the same refuelling hose.



A Buccaneer receiver about to make contact and to develop future refuelling equipment

The Mk XV hose-drum unit, as previously stated, was intended for the American Air Force. This did not come to fruition, however, and it was installed in the English Electric Canberra B Mk 2 bomber WH.734 for experimental purposes. It did very useful trials with virtually every receiver aircraft, as typically shown above.

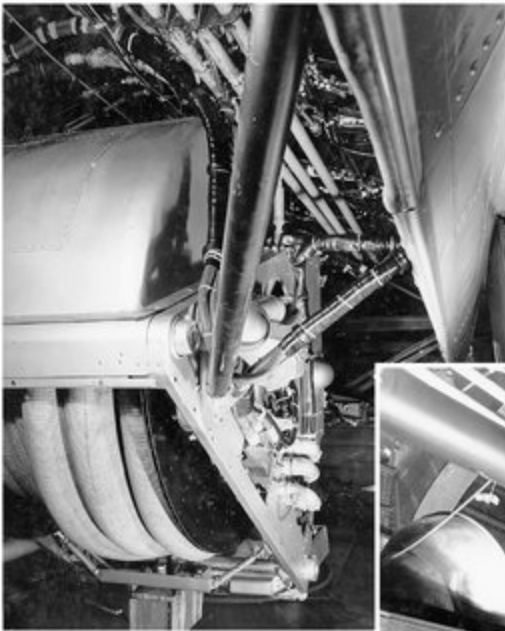
In July 1953 Canberra WH.743 was delivered to Tarrant Rushton for the installation of the Mk XV hose-drum unit for the high-speed and altitude trials with Valiant WZ.390.

The unit was installed at the forward end of the aircraft's bomb-bay, being suspended from its roof by four vertical, tubular struts, together with four side struts to absorb the side loads and two drag struts mounted at the forward end to absorb the high pull-off loads that would be applied when

the receiver aircraft broke contact. The two rear side struts were attached to the unit adjacent to the rear vertical struts, and secured to the bomb-bay longeron. Similarly the forward side struts were attached to the unit's point and thence to the longeron. The two drag struts were also attached at the unit's pivot point and to the longeron at the forward end of the bomb-bay. The photos show the port and starboard sides of the unit in situ.

The bomb-bay doors were completely removed and replaced with a long deflector board (below) centrally positioned within the bomb-bay, and faired in by a fabricated skin along its sides. This prevented the drogue rising into the bomb-bay during the winding and trailing sequences, as from past experience it had shown to rise during a short length of hose being trailed.

The control panel was located at the navigator's position, together with a rearward-looking mirror mounted externally on the port side of the fuselage. This permitted the operator to view the hose during an operation.



CHAPTER SIXTEEN

Mk XVI Air Refuelling Package

The leading particulars of the Mk 16 refuelling package were:

Fuel flow rate	500 imperial gallons per minute (2,250 litres or 4,000lb)
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Fuel pressure at reception coupling	50 psi (3.40 bar)
Operating voltage driving motor	
Actuators	

Current consumption, 40,000 feet Normal	112V DC
---	---------

running current (112 volts)	28V DC
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Motor speed	
Weight, hose and coupling dry	
Weight, hose filled with fuel	
Height including drogue	
Length including drogue	130 A
Width less drogue	
Width allowing for drogue maximum travel in each direction	6,000 rpm

Speed of hose-drum rotation	
Length of refuelling hose	1,117 lb

1,397 lb

60.55 inches (1,538 mm)

80.60 inches (2,047 mm)

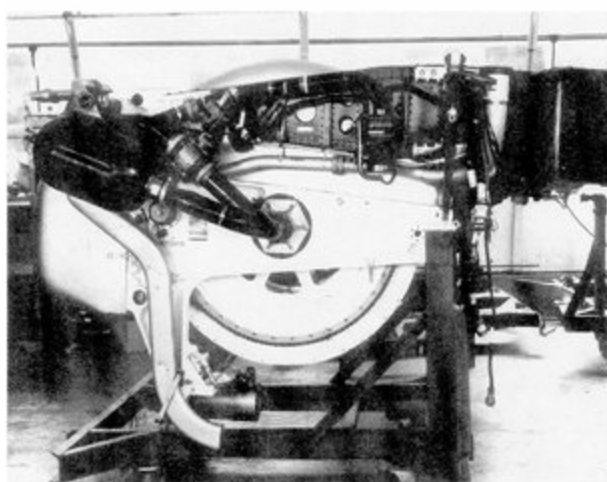
37.30 inches (948 mm)

48.00 inches (122 mm)

70 rev/min

105 feet (3,200 mm), later
modified

Bore of refuelling hose	3.00 inches (76 mm)
-------------------------	---------------------



The Mk 16 refuelling package, illustrated below, comprised the Mk XVI hose-drum unit and fuel-pumping and control system mounted to an A-frame structure for attachment as a fixed fitting (non-retractable) in the tanker aircraft. The hose-drum unit was a further development of the Mk XV hose-drum unit, having a modified drive system and hose-jettison capability, and the main structural components being cast in magnesium alloy to keep its overall weight to a minimum. The fuel pumping and control system were mounted above the hose-drum unit on an A-frame structure,

together with all the necessary fuel, air and electrical connections required for its operation.

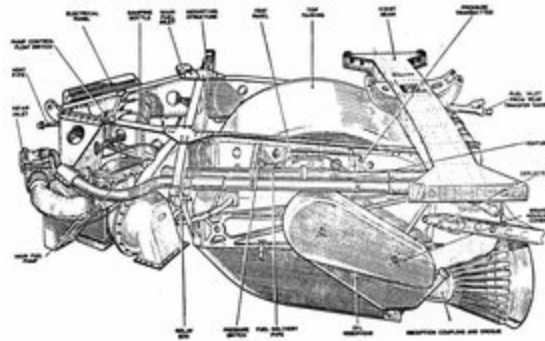


Fig. 128. Mk 16 refuelling package

The refuelling package's fuel-transfer system was designed with an automatic fuel flow to suit the requirement of each different receiver aircraft, and to maintain a constant 50 psi at the probe nozzle. The system could therefore refuel any type, providing the rate that it could accept, the flow rate being dependent on the design of the receiver aircraft's fuel system, e.g. in a fighter aircraft the fuel lines in its system would not necessarily be of a large bore, thereby restricting the flow. However, on large bomber or transport aircraft the bore of the lines could be increased without causing such a restriction. As an example of this, the Lightning could only receive fuel at 100 gallons (450 litres) per minute; however, the Avro Vulcan, having a large-bore fuel system, could receive at 600 gallons (2,700 litres) per minute, but with a lower pressure at the reception coupling and probe nozzle.

To enable the fuel transfer to be adequately controlled, the refuelling package incorporated a venturi pressure-sensing device, which was placed in the output line of its fuel pump. It was designed such that its pressure drop at the rated flow was identical to the pressure drop across whole fuel line, from the pump's outlet to the reception coupling at the free end of the refuelling hose. The venturi's throat was

connected to a servo mechanism incorporated within the fuel pump, which controlled the air supply to the turbine. If the servo was set to 50 psi (3.40 bar), any rise in pressure at the reception coupling would immediately be sensed at the venturi, and the air supply to the turbine was reduced, thus maintaining a constant 50 psi (3.40 bar) at the probe nozzle of the receiver aircraft under flow or no-flow conditions.

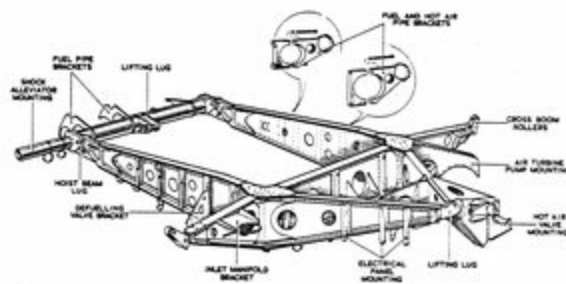
Several automatic safety devices were incorporated in the package system. In the typical system illustrated, the fuel pump was protected from overspeeding by a speed governor, a pressure-switch connected to the venturi throat, and the float-switch located in the inlet to the pump. The pump could not run without a fuel input from the tanker system, as the float fitted to the float-switch had no buoyancy, and so the electrical circuit to the hot-air gate valve was broken, and no air was admitted to the turbine. When fuel was admitted the float rose, thus reconnecting the electrical circuit and allowing the hot-air gate valve to be operated. If the pump's overspeed governor failed, the subsequent rise in fuel pressure operated the pressure-switch at the venturi throat, the electrical circuit being so interconnected that the hot-air gate valve closed, together with the closure of the fuel valve and opening of the vent valve in the main package output line. To protect the system from high transient fuel-surge pressures, caused by the sudden closure of the reception coupling's valve through an inadvertent or emergency disconnection of the receiver aircraft; a shock alleviator was incorporated in the output line adjacent to the hose drum's inlet.

The hose-drum unit support structure and fuel system has been briefly described in its operation in the paragraph describing the Valiant tanker. However, the three main components of the refuelling package were an A-frame structure, an H-beam (lifting beam), and the Mk 16 hose-drum unit/refuelling hose, reception coupling and drogue.

The A-frame structure ([Fig 129](#)) was of a prefabricated

construction, having lifting lugs located centrally at its forward and aft ends. At the rear end of the side booms of the structure were attachment holes to attach the structure to the H-beam, and tubular suspension struts of the hose-drum unit, as well as a cross-tube that had the aft lifting lug attached. Similarly, a cross-beam located half-way along the structure provided attachment lugs for the forward tubular suspension struts of the hose-drum unit. Also at each side extremity of the beam were spring-loaded rollers, which, when the package was installed, aligned with roller pads in the aircraft's bomb-bay roof. Beneath each roller a lug was mounted on the underside of the cross-beam to accept a side tubular strut for the hose-drum unit. Around the complete structure were various brackets located to accept the components of the package's fuel and control systems.

Fig. 129. A-frame structure



The H-beam, was also of prefabricated construction, being a cambered box girder with splayed ends and two central arms projecting laterally from its centre section. The centre section comprised four castings, which were bolted together, the two arms being bifurcated to form two pairs of lugs, these accepting steel pins for attachment to the bomb-bay roof. Located in the centre of the beam was an aperture, the side walls of which had a locating spigot for the aircraft bomb hoist to react against when lifting the package into the aircraft. At the splayed extremities of the beam were two

The convolution provided conformity to the shape of the first layer of hose and guided the second layer to its correct position. Located on the starboard side of the drum were the driving sprocket, which had an overall diameter of 37.14 inches (943 mm) and 154 teeth, and the circular electrical slip-ring carrier which connected the hose-jettison mechanism to the power source. In the centre of the drum hub, also on the starboard side, was a Flexibox rotary seal (Fig 131) which provided a fuel-tight joint between the hose drum and the main fuel system.

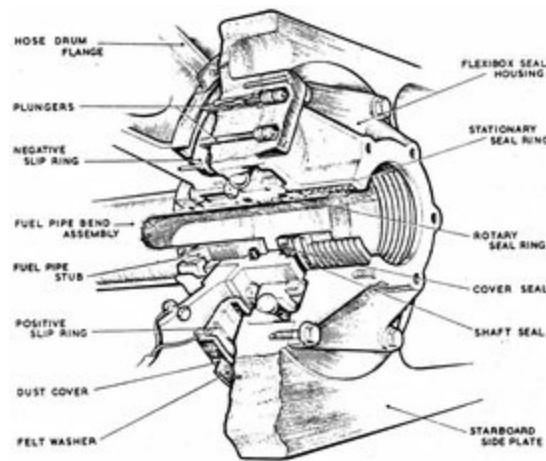


Fig. 131. Flexibox rotary seal

Connected to the rotary seal internally was a large fuel pipe, which in turn joined the hose-jettison mechanism via a hose adaptor. Within the pipe adjacent to the jettison mechanism was a spring-loaded poppet valve that opened automatically when the refuelling hose was engaged. The hose adaptor had six equally spaced holes bored radially through its periphery, each of which had a ½-inch-diameter steel ball, these holes being reduced at the inner surface of the adaptor, thus preventing the balls falling through. The outward movement of the balls was restricted by a steel release ring that was fitted over the hose adaptor. Six tapered slots on the inner surface of the ring formed ramps that forced the balls

inwards in the normal locked position; however, when the ring was rotated through 15 degrees they were released outwards. A lug formed on the periphery of the ring was connected to a spring-loaded operating rod of the hose-release jack assembly (Fig 132)

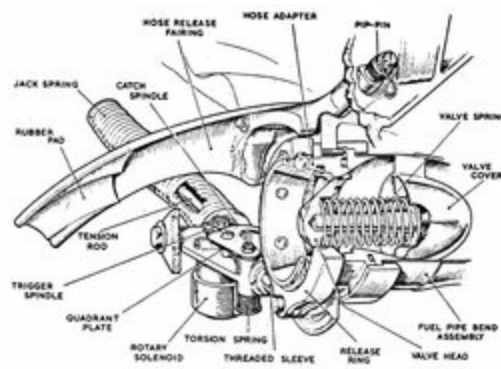


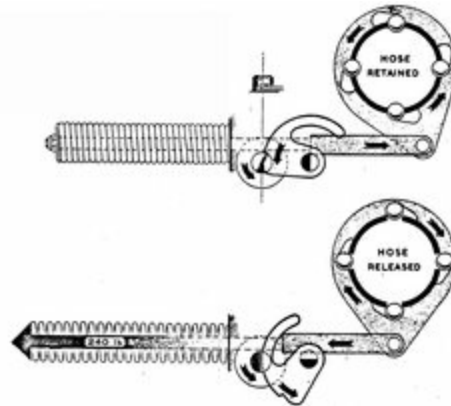
Fig. 132. Hose-release jack mechanism

The hose-release jack was mounted inside the hose drum barrel and parallel to its axis, on a special bracket. It comprised a light alloy body, a tension rod, which was a sliding fit within the body, a jack spring, a rotary solenoid and a trigger mechanism.

The spring, which was rated at 240 lb, was passed over the tension rod with one end seating against the body, and the other retained by a special washer secured to the rod. The opposite end of the rod had a screwed sleeve secured to it that was attached to the lug of the release ring. Two parallel bores within the body accepted a catch spindle and a trigger spindle. A light torsion spring mounted on the catch spindle provided a permanent bias, causing a quadrant plate to bear against the projecting end of the trigger spindle when the mechanism was cocked. The upper end of the trigger spindle was slotted, thus allowing it to be operated by a screwdriver during ground servicing, thus facilitating release of the hose, also a cut-out $\frac{1}{4}$ inch from this face allowed movement of the quadrant plate. The opposite end was connected to the

rotary solenoid. When the solenoid was energized, its armature rotated, turning the trigger spindle (Fig 133).

Fig. 133. Functional diagram of hose-release mechanism



The cut-out on the trigger spindle was thus brought opposite the quadrant plate, which in turn moved into a groove formed by the cut-out, as the catch plate rotated due to the action of the torsion spring, the threaded sleeve being of a greater diameter than the tension rod. It formed a shoulder that normally came against a flat machined on the catch spindle. The rotation of the latter released the tension rod, and consequently the spring. As the release ring fitted to the female hose adaptor was pinned to the screwed sleeve, the linear action of the sleeve and the tension due to the release of energy stored in the spring caused the release ring to rotate, allowing the six steel balls to move outwards, thus releasing the hose. A hose-release fairing was fitted over the hose-release mechanism to prevent the first layer of hose from fouling the edge of the hose release ring during the winding sequence.

The main drive assembly (Fig 134) was modified from that of the Mk XV hose-drum unit in that the driving motor was now at the top of the drive platform. Also, the primary drive was incorporated within a magnesium alloy cast housing, and introduced a fluid-drive oil-pumping system, together

with an oil reservoir. The basic drive assembly was similar in that it comprised five main components, namely:

1. Electric driving motor
2. Primary-drive assembly
3. Fluid-drive coupling, with electrically controlled scoop
4. Chain coupling
5. Two-speed gearbox and gearbox actuator.

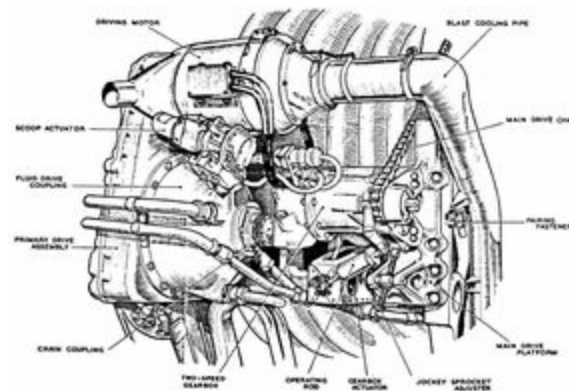


Fig. 134. Main drive assembly

The driving motor was a Rotax Ltd Exp. 5024 shunt wound 112 V DC motor rated at 15 h.p. at 50,000 feet, normal current 133 A at 6,000 rpm. It was blast-air cooled, flame proofed, and was fully screened, together with radio-interference suppressors. It was secured to the main drive platform with shims beneath its feet to ensure good alignment with the primary drive unit (Fig 135).

The primary drive was mounted on the left-hand side of the drive platform, the drive motor being attached to it at the top and a fluid drive at the bottom. The cast casing of the drive was manufactured in two halves, also in magnesium alloy. The assembly comprised a triplex drive chain, two chain sprockets and an adjustable jockey sprocket to ensure the correct chain tension. To enable the jockey sprocket to be adjusted, its mounting shaft protruded through the casing with the locking nuts.

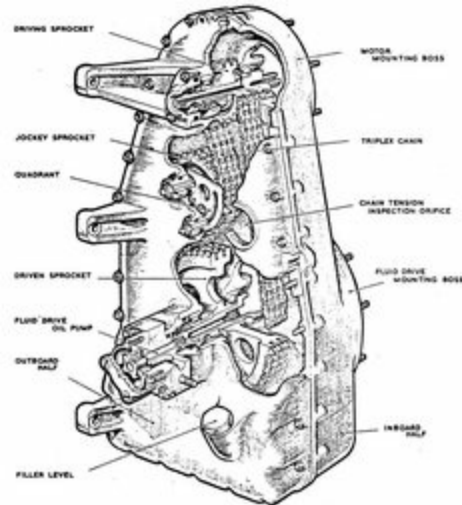


Fig. 135. The primary drive

Adjacent to it was a 1½-inch-diameter inspection hole, normally covered by a castellated nut; with the nut removed the chain tension could easily be checked and adjusted. Attached externally to the lower driving shaft on the left-hand side of the casing was a small gear pump, which was a self-priming type providing the oil flow required for the fluid drive. The fluid drive ([Fig 136](#)) was similar to that employed on the Mk XV hose-drum unit, and its principle of operation was the same. However, a modification was incorporated to improve and automatically control the operation of its scoop-tube, thus controlling the torque output. Where the tube projected through the coupling's housing, a sliding-arm mechanism by which a now rotary actuator was attached converted the rotary action to a linear action to raise and lower the scoop tube. Opposite the actuator a rotary potentiometer was also secured to the actuator's driving shaft. The operation of this control was through the electrical system of the hose-drum unit to a manual control in the cockpit on the control panel, thus making it automatic on the hose-drum unit. The real description of the scoop control is 'hose tension', which incorporated the variable rotary potentiometer coupled to the rotary actuator that

formed one half of a 'Wheatstone Bridge'. A similar manually operated potentiometer incorporated in the system on the cockpit control panel formed the other half of the bridge. Any movement of the panel potentiometer caused the bridge to be out of balance, and a small current (of the order of 30 microamperes) flowed in the circuit.

This circuit operated a sensitive moving-coil relay, which had a fixed contact at each side of the moving contact attached to the pivot coil. The out-of-balance current that flowed in the coil caused the moving contact to bear against the left- or right-hand fixed contact, according to the direction in which the hose tension control knob on the panel was manually rotated. Each of the fixed contacts of the relays was connected to a magnetic relay, and each of these brought into circuit one or two field coils of the rotary actuator. As these two field coils were wound in opposite directions, one would cause the actuator to move clockwise and the other counter-clockwise. Thus the direction of the actuator (and consequently the up-and-down linear movement of the scoop tube) was remotely controlled by the operator. The movement of the actuator, in either direction, transmitted an identical amount of movement to the potentiometer, and so the balance of the bridge was restored and the moving contact of the sensitive relay returned to its mid-position in readiness for the next scoop-control operation. During the winding-in sequence of the hose, the manual control was replaced by a preset automatic control, which ensured a constant winding-in torque.

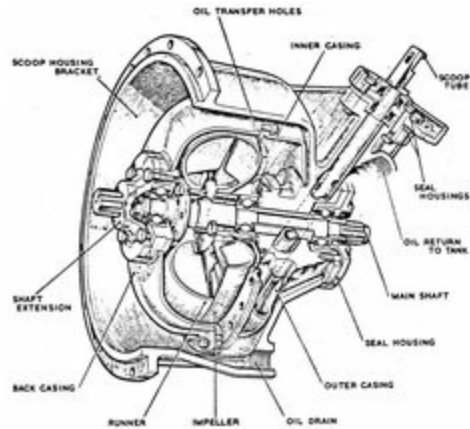


Fig. 136. Fluid-drive coupling

The oil pump (Fig 137) pumped oil from a reservoir mounted to the port side frame around a circuit (shown in Fig 38) to a thermostatic valve located on the inside of the starboard side frame. At oil temperatures between 38 and 50°C the valve gradually opened, allowing the oil to flow through a ram air cooler located centrally between the side frames at the aft end of the hose-drum unit. If the oil was less than 38°C; the oil was allowed to bypass the cooler and flow directly to the oil inlet of the fluid-drive coupling, and thence through the ports in the fluid drive to the inner casing and impeller.

The impeller, which was driven by the output shaft of the primary drive, acted as a centrifugal pump, transmitting power to the runner by the pressure of the oil vortex on the runner's vanes. The runner being secured to the main shaft of the coupling thus was transmitted to the two-speed gearbox via a chain coupling.

The amount of torque transferred was proportional to the quantity of oil in the working circuit, and this was varied by the raising and lowering of the scoop tube. The depth to which the scoop tube entered controlled the amount of oil bled away. When in the fully down position, the tube removed all the oil, the runner ceased to rotate and no torque was transmitted.

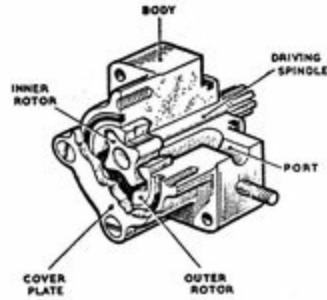


Fig. 137. Fluid-drive oil pump

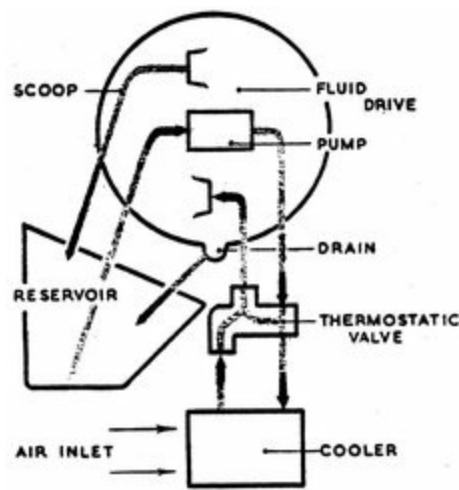


Fig. 138. Fluid-drive oil circuit

The chain coupling (Fig 139) coupled the fluid-drive coupling to the two-speed gearbox, which consisted of two equal pinions, internally splined to fit the output shaft of the fluid drive coupling and the input shaft of the gearbox. It was fitted with a duplex chain, permitting slight irregularities in shaft alignment but providing a positive drive.

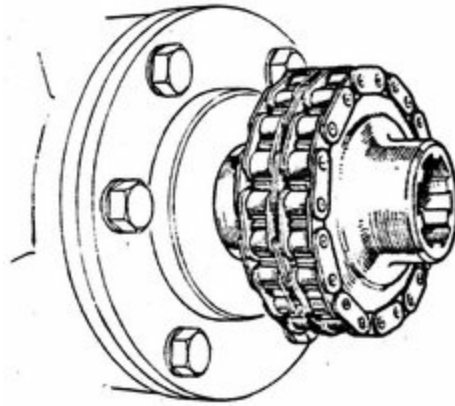


Fig. 139. Chain coupling

The two-speed gearbox (Fig 140) was secured to the lower and right-hand side of the drive platform, and similarly to the Mk XV hose-drum unit. However, the gear ratios were slightly altered, and where on the Mk XV the high gear ratio was 1:1.65 the Mk XVI was 1:1.915, and the low gear of 1:6.15 was now 1:70. A further modification due to the repositioning of the gearbox was the position of the gear-change mechanism. The Bell-Crank gear-change lever was now angled, and a similar actuator-mounting bracket to that of the Mk XV was introduced beneath the gearbox.

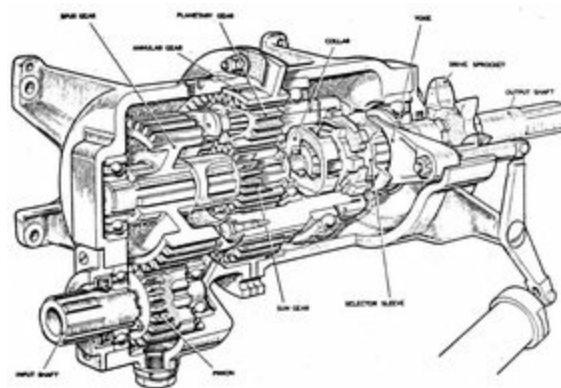
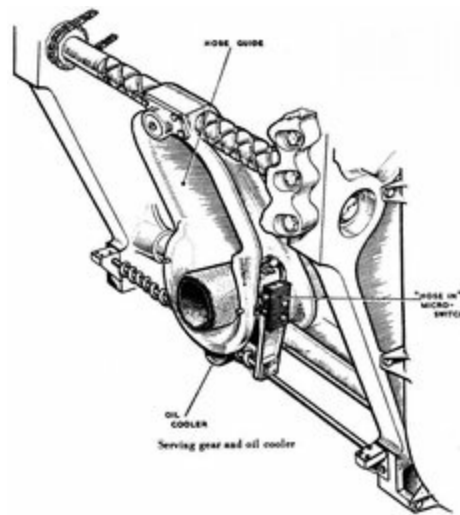


Fig. 140. Two-speed gearbox

The serving carriage, or hose guide (Fig 141), which ensured

the layering of the hose to the drum, was similar to that of the Mk XV, but it had a modified Archimedean drive shaft. The modification was introduced because of the hose footage transmitter being repositioned on the port side frame, together with improved electrical switching, the new assembly being termed a rotary switch unit.

Fig. 141. Serving carriage



The rotary switch unit ([Fig 141](#)) was a small assembly on the port side frame, driven via the Archimedean shaft contained in a cast bracket. One end of a worm shaft mounted in the bracket was machined to a rectangular section and engaged with a slot in the securing nut of the Archimedean shaft. A spring-loaded worm keyed to the worm shaft drove a worm wheel, which was integral with a camshaft mounted at right angles to it. Three cams mounted coaxially on the camshaft operated three microswitches immediately beneath them. The lowest cam secured to an adjusting plate, thus enabling its lobe to be adjusted by hand in relation to the other two. This particular cam operated the 'hose pre-stow' microswitch that switched off the driving motor at a predetermined position when in high gear, and also applied the brake when low gear was engaged, and two white lines

were engraved on the periphery of the cam to facilitate accurate adjustment. The second cam, which operated the fuel valve microswitch, was interlocked by a dowel to the third, which in turn was bolted to a flange on the camshaft and operated the full-trail microswitch. This initiated the operations of switching the driving motor OFF, changing gear and restarting the motor.

The driving spindle of a footage indicator transmitter of the ratiometer type was pinned to the worm wheel shaft, thus being driven by it. The transmitter was electrically connected to a footage indicator on the operator's control panel.

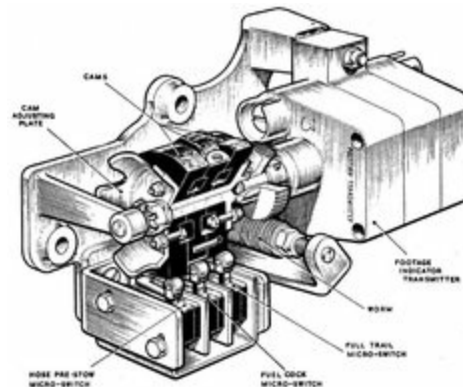


Fig. 142. Rotary switch unit

The brake mechanism ([Fig 143](#)) was also similar to that employed on the Mk XV but was repositioned, together with some further improvements.

The complete mechanism was rotated through 180 degrees, so that the liquid spring was no longer mounted at the forward end of the port side frame, but to the rear. The first improvement was the introduction of a twin rotary actuator, an improved emergency brake-locking device capable of holding the brake in the OFF position and instantly releasing it to the ON position when required. The twin actuator provided an additional safety feature in the event of an

actuator failure, for if one failed the second could still disengage the brake and avoid an aborted mission.

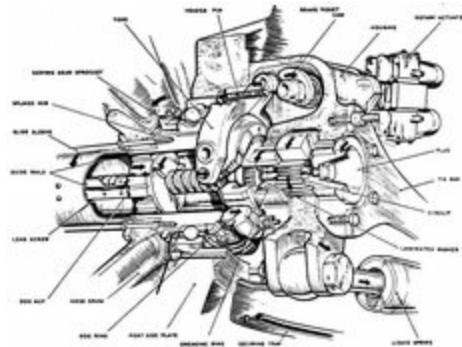


Fig. 143. Brake mechanism

The second improvement was the electromechanical device for holding the brake in the OFF position. Instead of the yoke having an extension and engaging with the solenoid's pin in a ramped slot; the new device incorporated a headed pin bushed into the brake housing in such a position that when the brake was applied it passed across a flat machined on the shaft of the brake-lock solenoid (Fig 144).

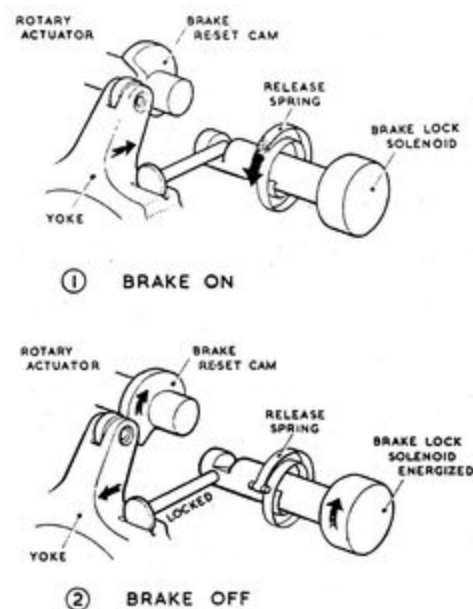


Fig. 144. Operation of brake lock solenoid

The head of the pin engaged with a slot in the yoke; when the electrical circuit was completed the solenoid imparted a rotary motion to the armature and shaft, but the shaft was prevented from turning by the pin. However, the movement of the yoke during its disengagement withdrew the pin, the shaft then rotated and the brake was locked in the OFF position. The spring-loading of the emergency-brake dog ring maintained a constant pressure on the yoke, and so the tip of the pin came against the shaft.

The electrical supply to the solenoid could be cut off by the following actions, and in each instance the emergency brake was automatically applied to ON. Firstly by the operator at the control panel, automatically by the speed control unit, the hose pre-stow switch, or the full trail switch the two latter switches being on the rotary switch gear unit, also through any electrical failure. The interruption of the electrical supply de-energized the solenoid the shaft of which rotated due to its return spring until the cut away portion was opposite the pin. Since the emergency dog ring was spring-loaded, its teeth were pressed into contact with those on the drum's hub, the same pressure acting on the yoke forced the pin across the shaft and locked the brake in the ON position.

A speed-control unit ([Fig 145](#)) was fitted to the starboard side frame and differed from that employed on the Mk XV hose-drum unit.

The unit contained a light alloy disc mounted on a shaft, which rotated in a gap between a pair of permanent magnets and a pair of keepers; a fibre pin-wheel to transmit the drive from the hose drum's drive sprocket to the disc; and a microswitch arranged to break the electrical circuit to the emergency brake's locking solenoid.

The body of the unit was a flanged cylindrical casting that

contained the spindle to which was mounted the fibre driving-pin-wheel and the alloy disc. Attached to the body was an axle plate that comprised the magnet-arm spindle and magnet arm. A bracket secured to the axle plate had a microswitch attached to one side of the magnet arm, and on the other two stop-screws, the switch being mounted in such a position that its actuating strip was in close proximity to the edge of the magnet arm.

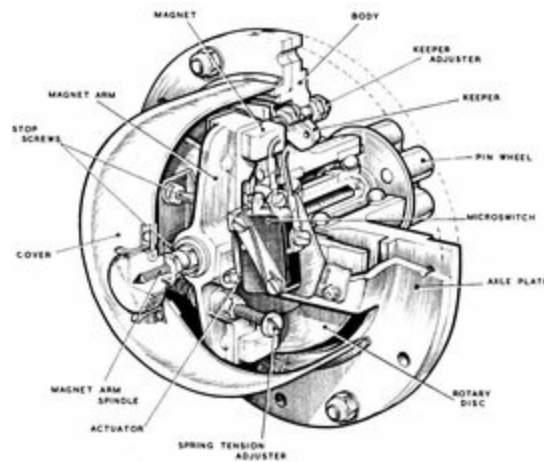


Fig. 145. Speed-control unit

The correct clearance between these two components was maintained by a 4BA screw, the tip of which butted against the magnet arm at a point just below its centre, thus preventing any movement in a clockwise direction. A spring anchored at one end to the axle plate and the other to a tension-adjusting screw fitted through the arm ensured that the arm returned to the vertical position after any movement.

During the hose-trailing sequence the drum's drive sprocket transmitted a rotary motion to the pin wheel, the light alloy disc spinning at speeds from 1,280 to 1,400 rpm. The eddy currents set up in the disc by the magnetic field imparted a drag to the magnet arm, which at normal speeds was insufficient to overcome the load applied to the arm by

the spring, so that it remained stationary. If the hose speed exceeded 5 to 8 feet per second, however, the increased speed caused the disc to spin at a higher rate, and the drag imparted to the magnet arm was sufficient to overcome the spring tension. The magnet arm then tended to rotate in a counter-clockwise direction (viewed from the cover end of the unit), and provided that the spring tension and magnet-arm adjusting screw had been correctly adjusted, the pressure of the arm against the actuating strip operated the microswitch. Thus the electrical circuit to the emergency brake solenoid was broken and the brake was immediately applied to the ON position.

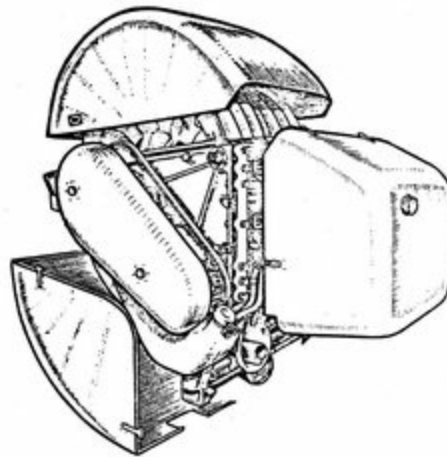


Fig. 146. Hose-drum unit fairing

When installed in the aircraft, the hose-drum unit was covered by fairings (Fig 146) to protect the component parts from exposure and to reduce drag during flight.

To facilitate access to the components during ground checks, the fairing assembly was divided into four parts:

Top fairing
Bottom fairing

Main drive fairing Brake housing fairing

The top fairing fitted over that part of the hose drum that protruded above the two side frames and was bolted to them.

The brake housing cover fitted over a securing tray with two knurled knobs that secured it to the tie bar of the brake mechanism.

The bottom fairing had four toggle-fastener housings, two near the lower rear corners and two at the forward end, and these engaged with toggle levers attached to the side frames.

The main drive fairing was similarly attached to the side frames and main drive platform. A circular aperture approximately in the starboard side of the fairing permitted a crank handle to be fitted to the drive system, enabling the hose drum to be turned manually during ground servicing.

The hose assembly originally comprised 105 feet (32,004 mm) of hose with specially designed adaptors fitted to each end. The 3-inch-diameter-bore (76 mm) rubber hose had a cotton covering, reinforced with 13 swg. The hose was painted white, with coloured bands at intervals to enable the receiver pilot to see how much hose was trailed at any moment. At 5 feet (1524 mm) from the end of the hose to the hose drum, three bands of fire orange, 1 foot (304.8 mm) wide and 1 foot apart, were painted on it.

From the commencement of these bands, further coloured bands of arc chrome 1 foot (304.8 mm) wide appeared at 10-foot (3,048 mm) intervals, with the exception of a 10-foot-wide band of chrome located between 30 feet (9,144 mm) and 40 feet (12,192 mm) from the hose-drum end.

Item B of the hose adaptors in [Fig 147](#) is shown as similar to those previously used, but item A was slightly different in

that the hose adaptor was extended and tapered with an annular groove and bridge piece. This provided the capability of the hose to open the hose drum's fuel valve, and enabled the hose to be jettisoned.

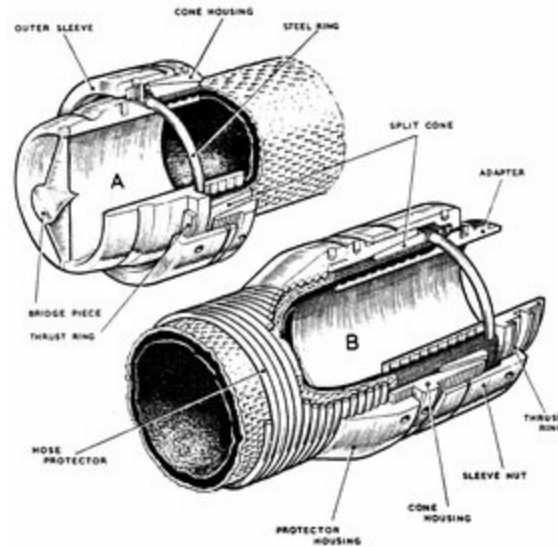


Fig. 147. Hose adaptors

During the early flight trials the hose tended to have severe vertical oscillations, which were unacceptable, and to overcome this problem the hose length was reduced to 80 feet (24,384 mm), which resulted in a very stable hose throughout the speed and altitude range.

Initially the Mk XVI refuelling package was equipped with the Mk 6 reception coupling, and the receiver aircraft with the Mk 6 probe nozzle ([Fig 148](#)).

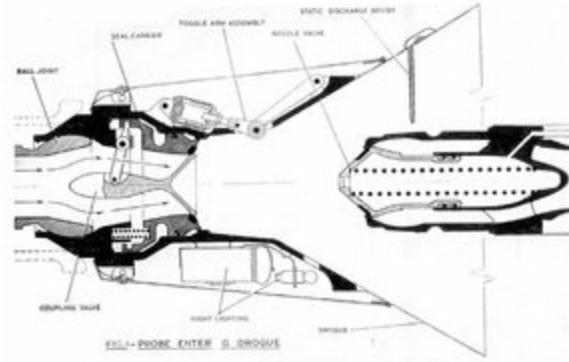


Fig. 148. Mk 6 reception coupling and probe nozzle

The coupling employed similar components to those previously described, i.e. the three spring-loaded locking toggles, night-lighting equipment, universal ball joint and the 60-degree included cone-drogue, but differed in its internal fuel-valve mechanism. The valve mechanism comprised a spring-loaded seal carrier with three toggle arms secured to a floating valve, and on the front face of the carrier was a nozzle/valve seal that provided the sealing surface for the probe nozzle when engaged with the reception coupling (Fig 149); it also provided the sealing surface for the coupling's internal valve when the nozzle was disengaged.

The Mk 6 probe nozzle retained a similar external profile to that of probe nozzles previously described, but the internal valve was now spring loaded. The internal three-legged streamlined spider that originally supported the probe valve stem now incorporated a cylinder to accept the valve and operating spring. At the rear of the cylinder and through one leg of the spider a vent hole was bored, being connected to the atmospheric line and so preventing hydraulicing of the valve when operated. The probe valve had a cylindrical stem with a bulbous streamlined head, the front face of which was conical to match the coupling's valve. A seal on the front face engaged with the periphery of the coupling's valve, again providing a fuel-proof joint.

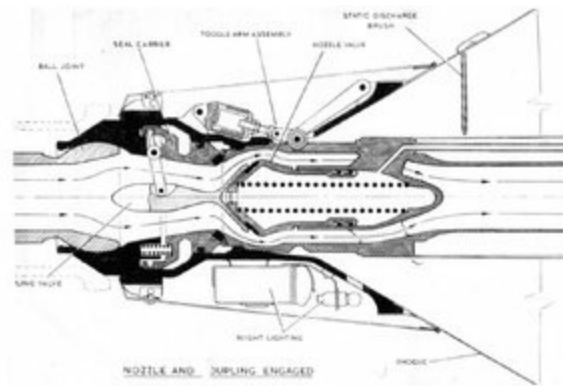


Fig. 149. Mk 6 probe nozzle engaged in Mk 6 reception coupling

When the probe nozzle entered the reception coupling, the coupling's toggles rode up the shallow ramp on the nozzle, its front face engaging with the coupling's seal carrier, and likewise the nozzle's internal fuel valve engaged the coupling's valve. As the nozzle continued to move forward, the seal carrier was automatically pushed forward against its springs and operated the coupling's valve toggle arms, thereby pushing the coupling's valve into the nozzle against its valve and spring, thus opening both components for a fuel transfer. The coupling's locking toggles finally allowed its rollers to engage the external annulus on the nozzle, thereby locking the two units together.

To ensure that the drogue was deflected downwards and clear of the aircraft's fuselage at the commencement of the hose-trailing sequence, a deflector assembly was attached to the rear of the hose-drum unit. This assembly consisted of a rigid platform, 64 inches (1,625 mm) in length, fabricated from light alloy sheets and tubes with reinforcing plates and stiffeners. The side members of the deflector terminated at their forward ends in the form of lugs, which were secured to the port and starboard side frames of the hose-drum unit. Two tubular stays supported the assembly at the correct angle, their upper ends being secured to the side members, the lower to the lower rear corners of the side frames.

The unit's contact lights were mounted in a single row across the forward transverse reinforcing plate of the deflector, facing aft. Where in the earlier concept of hose-drum-unit design the contact lights were amber and green, this later design incorporated red, amber and green lights for signalling the receiver aircraft. Each light was duplicated to ensure that the signalling was not interrupted by the failure of one light, each light also having two bulbs of different intensity for day or night operation.

Operation of the contact lights was similar to that previously described on the earlier units, i.e. with the hose at the full-trail position the AMBER light was illuminated, and when contact had been made with the hose having been pushed in the required distance the AMBER light was extinguished and the GREEN illuminated, indicating that the fuel was flowing. The introduction of the RED contact light was the only significant difference in the operation, and that was illuminated during the hose trailing and winding sequences, thus warning the receiver pilot not to make an approach or make a contact.

The refuelling package was remotely controlled from the operator's control panel, the fuel system of which has been described in the Valiant tanker. However, a brief description of the hose-drum unit operation is necessary, together with the electrical components.

The correct sequence of all the automatic functions was ensured through the circuit selector fitted within the hose-drum unit's relay panel. It was also energized at the appropriate times via the microswitches fitted in such positions on the unit that they were operated directly or indirectly by the movement of the refuelling hose.

The relay panel ([Fig 150](#)) was located on the front channel of the hose-drum unit and housed the electrical components. It was of an explosion-proof box construction, together with ventilation through flame traps. The box formed the body of

the panel, with a hinged, sealed lid manufactured from a light alloy pressing. Within the panel were five 20-way terminal blocks (two of these had resistors and common links attached) and a capacitor secured to the base of the panel; mounted on a chassis were the circuit selector switch and twenty-three relays, thirteen of which were used in the control circuits of the hose-drum unit, and also mounted on the chassis were the scoop control and gear-change delay circuit, five fuses and a further three capacitors.

On the centre panel of the lid a small square window permitted numbers on the circuit selector indicator disc to be viewed in turn as the switches rotated, this being used during ground testing of the trailing and winding of the hose drum. A rectangular aperture near the right-hand side of the panel's lid covered by a hinged flap enclosed a toggle-switch for ground test purposes. The switch's two positions were GROUND/FLIGHT, and the hinged flap could not be closed unless the switch was in the FLIGHT position. A label on the front face of the panel's lid was engraved with details of the functions of the hose-drum unit at each position of the circuit selector.

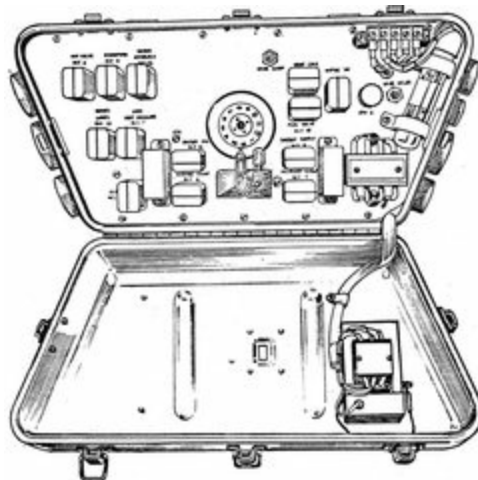


Fig. 150. Relay panel

The operation of the hose-drum unit and the fuel system of the package was dependent on the correct sequencing of the circuit selector switch ([Fig 151](#)) within the overall electrical system, and is not described in detail. However, to illustrate the operating sequences the position of the circuit selector switch indicates them very well.

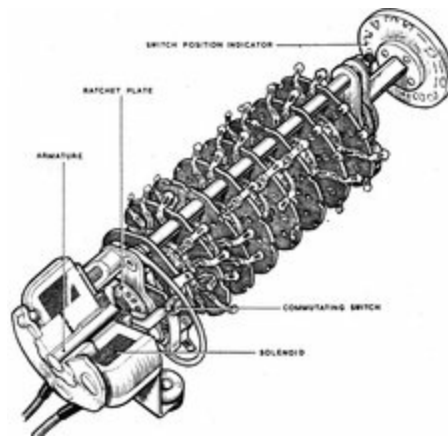


Fig. 151. Circuit selector switch

The following table illustrates the circuits selected through the circuit selector switch and relays:

Selector Position	Selector Switch Wafer Number	Circuit Selected
1.	3a, 3b	Hose tension 'TRAIL' selected at control panel indexes switch to 2
2.	3a, 3b	Hose tension control
	4a, 4b, 5a	Low gear

	6b	Emergency supply relay 'GEAR LOW' signal indexes switch to 3
3.	3a, 3b	Hose tension control
	5b	Brake 'OFF'
	6b	Emergency supply relay
	7a	Motor 'ON' 'FULL-TRAIL' signal indexes switch to 4
4.	3a, 3b	Hose tension control
	4a,4b, 5a	High gear
	6b	'GEAR HIGH' signal indexes switch to 5
5.	3a, 3b	Hose tension control
	5b	Brake 'OFF'
	6b	Emergency supply relay
	7a	Motor 'ON'
	7b	Fuel system Wind selection at control indexes switch to 6
6.	3a, 3b	Hose tension control
	4a, 4b, 5a	Low gear
	6b	Emergency supply relay 'GEAR LOW' signal indexes switch to 7

7.	3a, 3b	Hose tension control (Scoop travel preset)
	5b	Brake 'OFF'
	6b	Emergency supply relay
	7a	Motor 'ON' Pre-stow signal indexes switch to 8
8.	3a, 3b	Hose tension control (Scoop travel preset)
	6b	Emergency supply relay
	7a	Motor 'ON' 'Hose In' signal indexes switch to 9, 10, and 11
11.	3a, 3b	Hose tension control
	7a	Motor 'ON' with motor switch at 'Warm' Selection at control panel indexes switch to 12 and 1

Relay No.	Location	Function
1.	Relay Panel	Gear-change delay
2.	Relay Panel	Brake overspeed control
3.	Relay Panel	Driving motor 'ON'
4.	Relay Panel	Air gate valve actuator
5.	Control Panel	Fluid-drive scoop control

6.	Relay Panel	Scoop increase
7.	Relay Panel	Scoop decrease
9.	Relay Panel	Vent valve actuation
10.	Relay Panel	Emergency signal light (RED)
11.	Relay Panel	Emergency DC supply
12.	Control Panel.	Port under-wing tank
13.	Control Panel.	Starboard under-wing tank
14.	Control Panel	Master relay interlock
15.	Control Panel	Master relay (Power ON)
16.	Relay Panel	Brake actuator
17.	Relay Panel	High fuel-pressure control
18.	Relay Panel	Fuel valve actuator
19.	Deflector.	Dimming GREEN/AMBER contact lights
20.	Deflector.	Dimming RED signal light
21.	Control Panel	Master relay 115V AC supply (flowmeter)
22.	Relay Panel	GREEN contact light control
23.	Relay Panel	Brake interlock

A further electrical panel (Fig 152) housed the starter and contactor for the hose-drum driving motor, the shunt for the ammeter (hose-tension indicator) on the operator's panel, the flowmeter integrator and a Simmonds automatic density corrector.

At each movement of the circuit selector switch rotors, the numbered disc fitted to the switch shaft indicated the position of the rotors through the aperture in the cover of the relay box. This enabled the operation of the switch to be checked during ground servicing. Similarly, during a flight operation, the positions were indicated to the operator by a 'Circuit Selected Indicator' fitted to the control panel. This was a solenoid-operated 'homing' device, which rotated an engraved disc indicating the position of the hose drum by exhibiting a different word in a window near the centre of the control panel at each movement of the main selector switch. Sections 3b and 8a affected control of the indicator. In the event of a failure of the switch to index to the next position, the operator pressed the 'Stand-by Selector Switch', which prevented it from completing more than one turn.

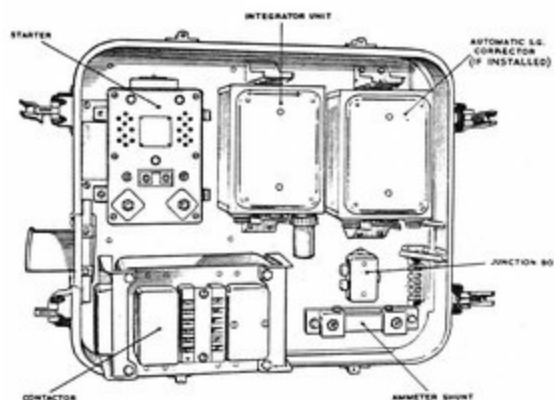


Fig. 152. Electrical panel

There were two separate 28 V power supplies to the control panel—the NORMAL supply and the EMERGENCY supply. The master switch on the control panel was in series with the aircraft 'Bomb-doors OPEN' microswitch, and so the power circuits could not be completed until the bomb-doors were fully OPEN, as the driving motor of the hose-drum unit could not run without cooling air.

When this microswitch and the master switch were both closed, Relay 14 in the system was energized, and this in turn completed the circuit to Relay 15, which switched on the normal supply. Relay 11 was continuously energized while the hose was trailed via the 'Hose Release' fuse and Section 6b of the circuit selector switch. The branch circuit connected by this relay prevented closure of the bomb-doors during the hose-trailing sequence and permitted hose jettisoning, fuel-valve control and the switching of the RED stand-off warning lights, whether the normal or emergency supply was in use.

The hose drum's driving motor was operated from the aircraft's 112 V DC supply via a contactor and starter, when the motor switch on the control panel was selected to 'Warm' and the ground test switch to 'Flight', Relay 3 was energized and completed the 28 V circuit from the 'Motor and brake control' fuse to the contactor, which then closed and applied 112 volts to the starter, which short-circuited the surge-limiting resistor and started the motor. A pair of back contacts on the starter simultaneously connected the 20 V supply to the 'Brake OFF' circuit. Another pair of contacts opened the gear-change control circuit, thus preventing a gear change occurring while the motor was running.

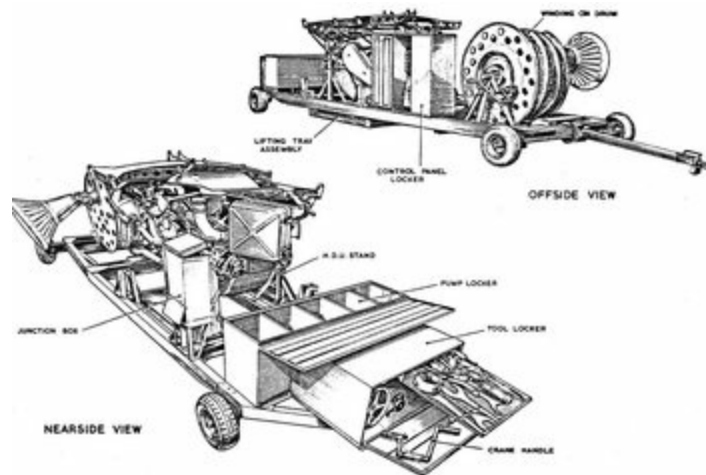


Fig. 153. Mk XVI package ground handling trolley

The torque that the driving motor was required to apply to the hose drum during trailing or winding sequences was proportional to the drag load on the hose, and this in turn depended on the speed of the aircraft. As the current consumption of the motor varies in proportion to its load, it increases or decreases with the aircraft speed. The ammeter connected to the negative lead of the 112 V supply to the motor was therefore used as a 'hose tension' indicator and was calibrated in knots.

To enable the Mk XVI refuelling package to be serviced, and to facilitate installation in the tanker aircraft, a ground handling trolley ([Fig 153](#)) capable of carrying the complete package, together with a stowage for ancillary and ground servicing test equipment, was manufactured. The trolley also incorporated a receiving drum upon which the refuelling hose could be wound during the servicing. A lifting tray that could be manually raised or lowered accepted the package, thereby facilitating its installation into the aircraft.

The leading particulars of the trolley were:

22 feet 3 inches

Overall length	(6,782 mm)
Overall height (including package and lifting Tray lowered)	5 feet 1 inch (1,549 mm)
Overall width	7 feet 7 inches (2,311 mm)
Tyre size.	7 inches x 18 inches (178 mm x 457 mm)
Maximum towing speed	7 mph

The rectangular chassis had a towing arm and four pneumatic-tyred wheels, and was constructed from steel channel sections. At the rear end, the chassis was extended beyond the wheels and triangulated. A parking-brake lever pivoted to a short longitudinal member was connected by a linkage to both of the rear brakes. The brake handle, which projected through a slot in the chassis, was moved rearwards to the parked position. The towing arm was hinged and pivoted to the forward cross-member, this end of the arm being connected to the Ackerman steering linkage controlling the front wheels, which had a minimum turning radius of 9 feet (2,743 mm).

The lifting tray was mounted on four threaded, rotatable, vertical shafts bolted to the chassis, which engaged with internally threaded sprockets at each corner of the tray. The sprockets were interconnected by a chain, which was tensioned by two auto-adjusters and passed through a conduit. The upper end of one of these shafts was formed to receive a handle by which the lifting tray was raised or lowered manually, each shaft incorporating a limit stop.

The refuelling package was carried on the trolley on a steel stand, together with a tubular stand at the forward end, which had the ground receiving drum mounted to it.

Incorporated within the drum was a Girling brake, which had a handwheel that, when turned, gradually applied or released the brake. When the refuelling hose was manually wound onto the drum via a chain drive; the reception coupling and drogue was clamped into a slot, the drogue protruding outboard.

Lockers were mounted to the trolley chassis for the stowage of ancillary equipment. Forward of the package on the port side was the control panel locker; and on the starboard side aft was the electrical junction box, to which an external electrical supply could be connected. One end of an electrical loom could also be joined from the box to the control panel. Thus a full ground check could be carried out on the package, with each function being checked.

A fuel pump locker for the five tanker conversion units was located at the rear end of the trolley, together with a special tool locker. Some of the special tools are shown in [Fig 154](#). The pull-off tester was for checking the load on the reception coupling toggles when the probe nozzle was disengaged, and the ground discharge adaptor checked the fuel pressure at the reception coupling; also, if the package's fuel pump was being run by closure of the aero valve, its control could be checked. The stall load tester checked the torque load applied to the drum by varying the scoop tube position on the fluid drive with the driving motor running, and during this testing a ground blast-air unit supplied the cooling air to the motor.

To illustrate how well the air refuelling equipment could be maintained during any ground servicing, the tools required have been listed below. This was necessary as this equipment had never been in service.

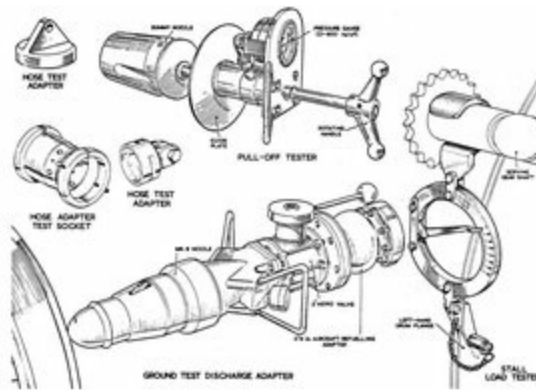


Fig. 154. Special ground servicing tools

Item	Use
Pipe blank, 4-inch diameter	For blanking fuel pipes, when pressurizing
Pipe blank, 2½-inch diameter	The fuel system
Cocking lever	For resetting hose-jettison mechanism, when changing refuelling hose
‘C’ spanner (2-off)	To tighten hose adapters
Ring spanner	
Oil cooler and motor blast air-cooling assembly	An air supply line was connected to the assembly for functional testing of the hose-drum unit
Crank handle	To wind manually the hose onto the hose drum and ground trolley receiving drum; also to raise and lower the trolley lifting

	tray
Hand gun charging assembly	For charging liquid spring on hose-drum brake
Test socket	For hose drum
Test adapter	For reception coupling
Test blank	For pressurizing the reception coupling
Load-testing lever and spring-balance	For checking reception-coupling ball housing
Test blank assembly and adapter	For pressurizing the probe nozzle on receiver
Toggle-release tool (3-off)	To disengage the defuelling adapter or slave nozzle from reception coupling
Tie rod (2-off)	To support deflector
Oil OM15 (1 gallon, or 4.5 litres)	For fluid drive, gearbox, chains and liquid spring
Oil OM13 (1 gallon, or 4.5 litres)	For primary drive on hose-drum unit
Grease XG-295	For all bearings

The following equipment was for bay servicing of the package or when the package was removed from the aircraft.

Item

Use

Hoist beam	For lifting complete package
Mk XVI hose-drum unit sling	For lifting basic hose-drum unit
'C'-type peg and key spanners	For servicing the liquid spring
Special screwdriver	To rotate cam on the brake mechanism
'C' spanner	To tighten ring nuts of defuelling valve/hose adapter
Spanner	To tighten hose-drum unit nuts
Hose-clamping block (2-off)	To service hose adapters
Gauge	To locate master seal in reception coupling
Oil OX38	To lubricate air turbine fuel pumps

When a function test indicated that a component was unserviceable, it was removed from the hose-drum unit, which could be achieved with the unit installed in the aircraft. No special tools were required, other than those supplied as ground equipment with the handling trolley.

So that a joint exercise of in-flight refuelling could take place between the Royal Air Force and the American Strategic Air Force, it became necessary for the refuelling equipment to be made compatible. The Americans were, as previously mentioned, using the MA.2 air refuelling

equipment on their naval aircraft, while the Royal Air Force used the British Mk 6. Eventually it was agreed to use the American-type equipment. However, the MA.2 equipment did not retain the American designation, but became the British Mk 8. As this equipment was first in use on the Mk 20A refuelling pod, the Valiant's reception coupling was given the designation of Mk 8a. However, as the aircraft was also a receiver, the probe nozzle that was designated as the Mk 8 is also described. The equipment operated in a similar manner to that of the Mk 6, in that the internal valves of both the coupling and nozzle opened automatically when a contact was made, as shown in [Fig 155](#).



[Fig. 155](#). Functional diagram, Mk 8 probe and reception coupling

The probe nozzle ([Fig 156](#)) comprised a nozzle shell that enclosed a spring-loaded sleeve valve, and concentrically supported a fixed shaft with a domed nose piece. The shell had an external annular groove to locate the toggle rollers of the reception coupling and was recessed at the forward end to accept two latching levers, which engaged in an annular groove in the outer sleeve of the sleeve valve. The sleeve valve comprised two concentric sleeves that were a sliding fit in the shell, the inner sleeve having three vanes forming the support for a shaft to which the domed nose piece was attached. At the rear end of the nozzle a further shaft-support block had a sleeve stop secured to it. The aircraft probe comprised a structural probe tube to which a nozzle adapter was secured at the forward end, and an inner fuel pipe supported on blocks within the structural tube,

connected to the nozzle by a standard flight refuelling pipe connector. The nozzle was attached to the structural tube by two half clamps locked together by a clamp retainer ring.

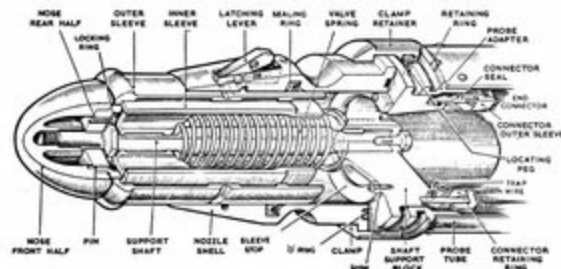


Fig. 156. Mk 8 probe nozzle

When the probe nozzle entered the reception coupling, the projecting ends of the two latching levers were pressed inwards by impact with the steel liner of the coupling's body. As the levers were pivoted from their mid-position, the toothed ends were thus lifted and disengaged from the outer sleeve. The rim of the outer sleeve then impinged on the seal ring in the reception coupling, and the sleeves were forced back against the spring. Simultaneously, the dome nose piece forced open the poppet valve within the coupling; when both valves were fully opened, the coupling's toggle rollers engaged the annular groove of the nozzle shell, thus locking the two together. To disconnect the probe with no fuel flow and pressure, the load required was 320 lb; however, for an emergency disconnect with fuel flow and pressure, it required 800 lb, as the locking toggles were pressure assisted.

The Mk 8a reception coupling ([Fig 157](#)) comprised a cast flared body, flanged at its forward end for the attachment to a universal ball joint, the ball joint, a spring-loaded poppet valve, three toggle roller assemblies, night lighting, a protective fairing, and the drogue. The forward end of the flared casting had secured to it the poppet valve housing, the ball joint and the ball joint housing. Internally within the

ball joint housing were two poppet valve springs, together with the poppet valve, the latter sealing against a master seal ring retained by a seal retainer held in position by three retaining screws. The three locking roller toggles were similarly spring loaded, like the earlier couplings. However, on the Mk 8 the springs were housed within a sealed cylinder and piston, which were connected to the fuel chamber of the coupling. Thus, when fuel was being transferred, the 50 psi fuel pressure was applied to the three pistons, thereby increasing the locking load to the probe nozzle. At the rear end of the flared body casting three night-lighting dynamos were equally spaced around its periphery, each being connected to two 6 V lamps, together with a 20-ohm resistor. Each dynamo was driven by a six-bladed propeller that protruded through the coupling's fairing. The lamps were located opposite holes in the cast flared body, thus illuminating the coupling's interior for night operation. Attached at the forward end of the coupling was a buffer spring with a striker plate; the plate made contact with a spring-loaded plunger on the hose-drum-unit serving carriage, which switched a microswitch indicating that the coupling was in the fully stowed position

It is worth noting that this particular Mk XVI air refuelling package was the first of its type capable of transferring and controlling automatically fuel at a nominal flow rate of 500 imperial gallons per minute, and maintaining a constant 50 psi fuel pressure at the reception coupling under full flow or no-flow conditions.

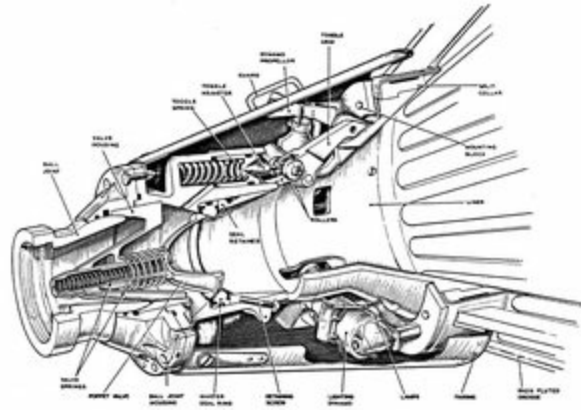


Fig. 157. Mk 8a reception coupling and drogue

CHAPTER SEVENTEEN

Mk 17

Refuelling Package

The origin of the Mk 17 refuelling package came from Air Staff Standard of Preparation Document No. 50, dated May 1962. Initially consideration had been given to the Mk 2 Valiant to become a three-point tanker aircraft, but when this did not materialize, consideration was given to the Handley Page Victor 1 bomber, which was eventually approved. This came about as the later Mk 2 Victor was about to come into service, and the Mk XVII refuelling package was proposed for the centre-line unit, and to be retractable. Again this package was to be an improved variant of the Valiant's Mk XVI package from the experience gained from the Valiant's successful air refuelling operations. As shown below, the package did not look very different from the Mk XVI that is shown in the test rig.



The specification for the package was the same as the Mk XVI, and it comprised the MK XVII hose-drum unit, fuel-

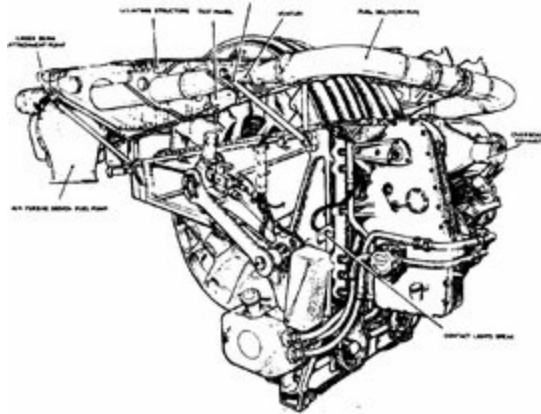


Fig. 159. Mk 17 refuelling package, starboard side

The fuel-transfer system located around the A-frame structure was slightly modified, the fuel shock alleviator bottle being kept on the starboard side but moved forward, as shown in [Fig 160](#).

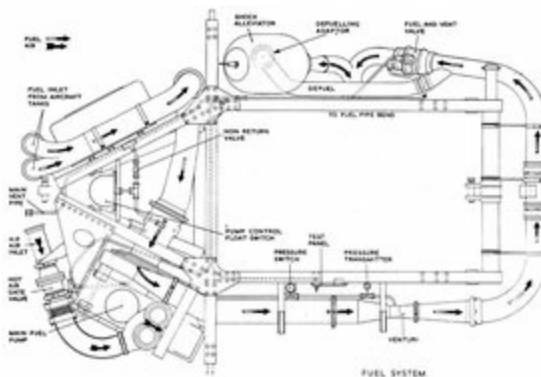


Fig. 160. Mk 17 revised fuel-transfer system

The basic hose-drum frame assembly was similar to that of the Mk XVI, all of the components being cast in magnesium alloy, but the side frames were modified slightly to provide more depth for the hose serving carriage.

Similarly the hose drum was identical to that of the Mk XVI, the only change being in the assembly, in that the internal fuel-pipe material was changed to stainless steel in

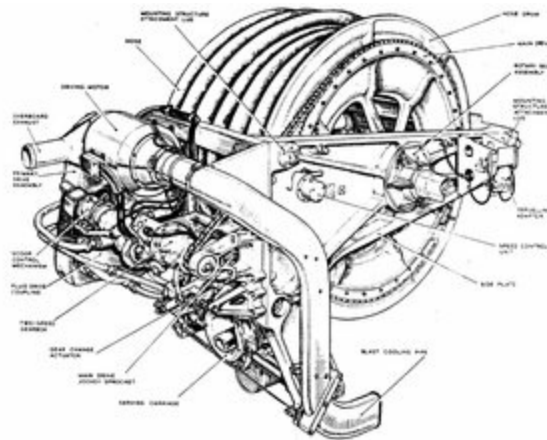


Fig. 161. Mk 17 hose-drum unit, port side

The main drive (Fig 163) was mainly the same, with an improvement to the fluid-drive scoop-sensing device, and an improved hydraulic oil reservoir.

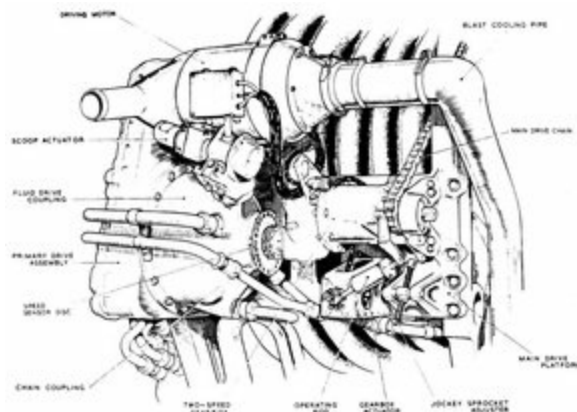
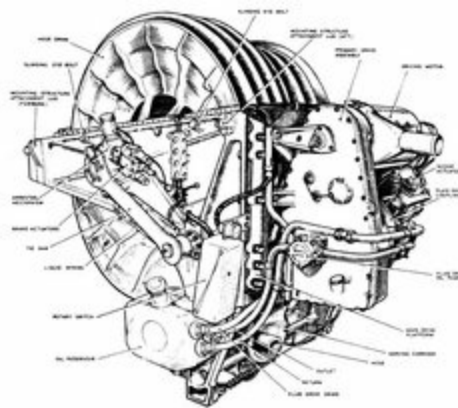


Fig. 163. Mk 17 hose-drum unit, main drive

The main drive was still powered by a 15 h.p. 12 V DC continuously rated motor, driving through a primary reduction to a trimming-type fluid coupling of which the torque output was now electronically controlled by a pulse generator speed sensor that sensed the speed of the output

shaft. Thus the trailing, response and winding speeds were automatically controlled and no longer manually controlled by the operator. The hydraulic fluid supply was taken from a repositioned reservoir on the port side of the hose-drum unit. The pumping and temperature control of the fluid remained the same as that employed on the Mk 16 hose-drum unit.

The hose drum braking mechanism ([Fig 164](#)) was an improved version of that used on the Mk 16 in that its emergency operation was much improved. The emergency brake still operated when a hose drum overspeed or an electrical failure occurred, but the operation was now controlled via a brake-lock solenoid being added to the assembly, which held the brake in the 'OFF' position during a normal operation, and released it to engage in an emergency, as shown in [Fig 165](#).



[Fig. 162](#). Mk 17 hose-drum unit, starboard side

solenoid plunger aligned with a set of steel balls housed within an integral spigot on the solenoid's base plate. When the solenoid was energized the armature forced a ball locking-ring down to trap the balls in the plunger's groove. The actuator having completed its travel, the brake was thus held in the 'OFF' condition, and when the solenoid was de-energized the brake was automatically applied.

The electrical slip-rings for the hose-jettison mechanism were repositioned, being fitted to the ends of the brake mechanism's lead screw and slide sleeve respectively (see [Fig 166](#)). The 28 V DC supply was therefore supplied to the mechanism whether the hose drum was rotating or not.

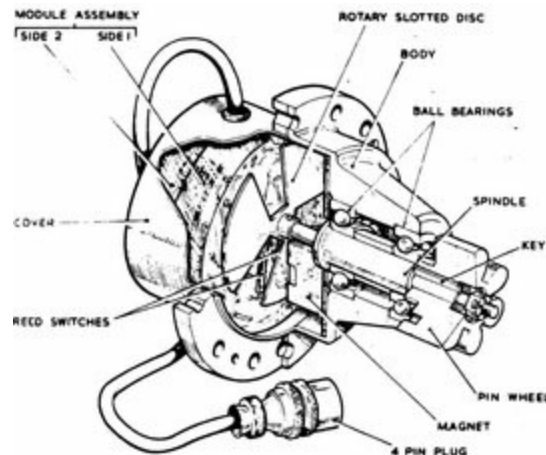
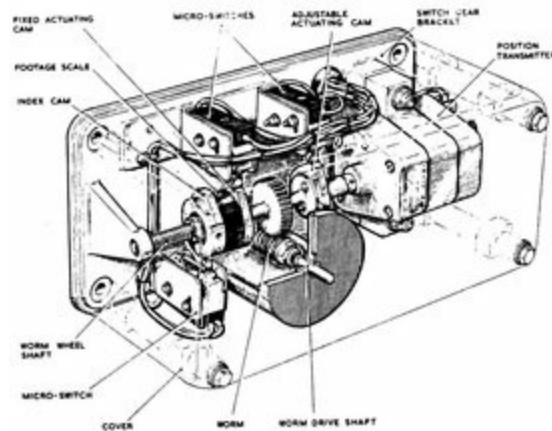


Fig. 166. Mk 17 hose-drum unit, speed control unit

A redesigned and simpler overspeed control unit was fitted to the starboard side frame of the hose-drum unit that prevented the refuelling hose from trailing too fast. The rotation of a slotted disc resulted in the interruption of a beam of light that fell onto a photo diode to produce a pulsed output, the frequency of which was dependent on the hose drum's speed. These pulses were added electronically to produce pulses of ½-second duration to break the electrical circuit to the brake mechanism's solenoid, thus applying the brake. At a normal trailing speed of 3 feet per second, the

frequency of the pulses was insufficient to break the circuit.

The rotary switch unit was also modified, as shown in [Fig 167](#), and was mounted vertically on the port side frame, being driven via the hose-drum unit's Archimedean shaft for the hose serving carriage. One end of a worm shaft mounted in plain bearings in the assembly's bracket was machined to a rectangular section that engaged with a slot in the end of the Archimedean shaft. A spring-loaded worm keyed to the worm shaft and retained by a stiffnut drove a worm wheel that was integral with a camshaft mounted at right angles to the worm shaft on the same bracket.



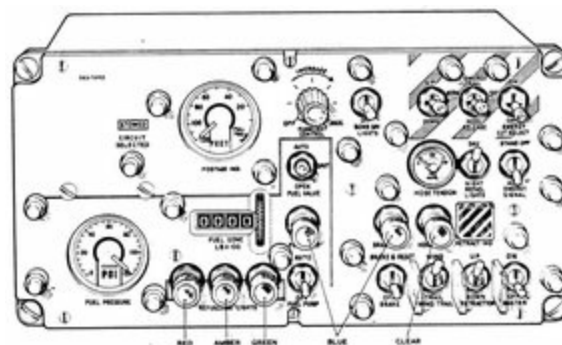
[Fig. 167](#). Mk 17 hose-drum unit, rotary switch unit

The new assembly operated in a similar manner to that of the Mk 16 hose-drum unit, in that it also had three cams operating microswitches, the latter being supported in U-brackets. The upper cam operated the full-trail microswitch, and was adjustable to allow for adjustments in relationship to a second cam for the fuel and vent-valve microswitch. This cam was fixed and bolted together with a hose footage scale, to a similar flange below the wheel; the scale acted as a spacer providing a boss on which an index cam was rotated for final adjustment. Two white index lines were engraved on the periphery of the index cam, which was adjusted so that

the hose pre-stow microswitch operated when approximately 70 feet of hose was wound in. The full-trail microswitch initiated the operations of switching the driving motor off, changing gear and restarting the motor. The fuel and vent-valve microswitch opened the fuel valve and closed the vent valve when the hose was partly rewound to within 6 feet of full trail. The pre-stow microswitch switched off the hose-drum driving motor at a predetermined position of the hose when in high gear, and also applied the hose drum brake when low gear was engaged.

The Mk 17 air refuelling package control panel was engineered to suit the installation in the Victor B Mk 1 aircraft, and is shown in [Fig 168](#).

The control panel comprised all the necessary switches, indicators and emergency switches for controlling the Mk 17 air refuelling package remotely.



[Fig. 168](#). Mk 17 air refuelling package, control panel

Tabulated below are the switches and indicators that were incorporated, the operation of which is included in the Victor tanker description.

Master switch

Fuel pressure indicator

Retraction switch

Footage indicator

Emergency retractor switch	Fuel Gone indicator
Wind/trail switch	Circuit Selected indicator
Brake switch	Hose-tension indicator
Emergency signal switch	Refuelling lights
Refuel lights switch	Pump OFF indicator
Emergency trail switch	Brake ON indicator
Emergency circuit selection switch	Hose IN indicator
Fuel pump switch	Wing flood light control
Fuel valve switch	
Bomb-bay lights switch	

The whole panel was illuminated by means of a 'Plastek' transilluminated panel.

Owing to the refuelling package now being enclosed within the aircraft's bomb-bay with the door closed, it was no longer necessary for the hose-drum unit to be enclosed within fairings, and so the complete set of fairings was removed.

CHAPTER EIGHTEEN

Mk XIX

Refuelling Package

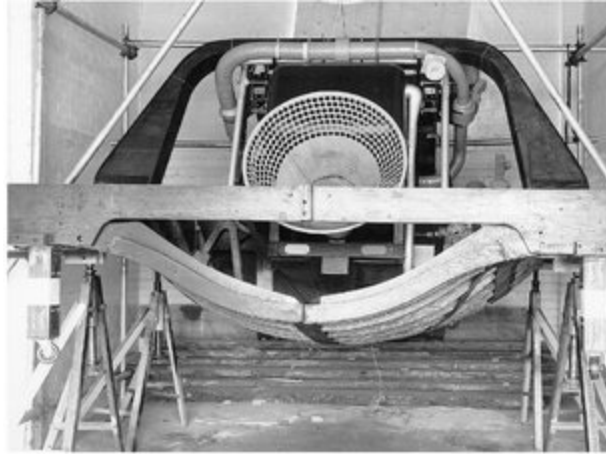
The Mk XIX refuelling package was designed to refuel the Handley Page 99 low-level bomber capable of carrying a nuclear deterrent.

The package was to have the capability of transferring fuel at 1,000 imperial gallons (4,500 litres) per minute from Victor or Vulcan tankers, and it was the intention that the HP 99 would take off with a light fuel load, and then refuel, taking on 90,000 lb (11,250 imperial gallons, or 50,625 litres) of fuel in a single refuelling operation.

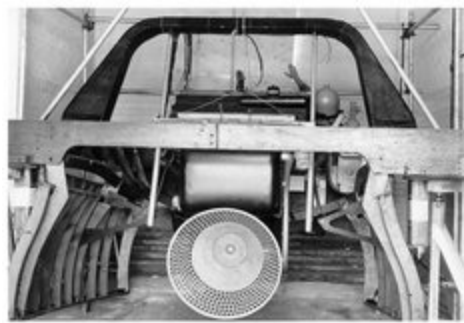
This requirement involved a completely new package, especially the fuel transfer system; and this, in turn, affected the refuelling hose size, and the pumping arrangement. Also, the hose-drum unit within the package structure was to be retractable, the whole assembly being capable of installation in either tanker's bomb-bay. As an interim measure to speed up the tanker installation, the Mk XVI Valiant hose-drum unit was to be installed in the package's structure.

To ensure that the interface connections and the package's structure aligned with the tanker aircraft, a full-scale mock-up was produced, which incorporated the Mk XVI hose-drum unit. The mock-up package is shown below with the hose-drum unit in the retracted position. The view is from the aft end, with the fairing doors closed.

Mk XIX refuelling package mock-up unit retracted



Similarly, below the unit has been lowered, and the fairing doors are open ready for the refuelling hose to be trailed.



Mk XIX refuelling package mock-up unit lowered

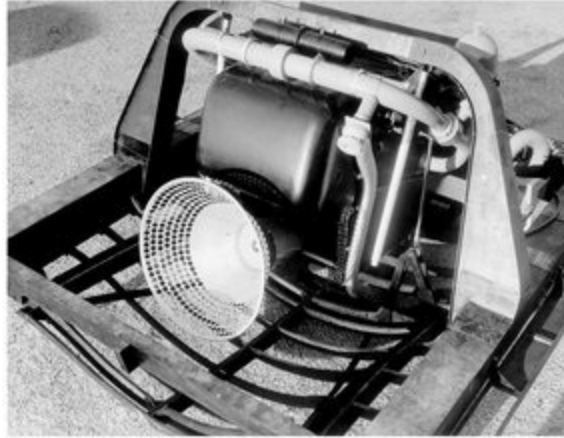
The structure of the package was basically rectangular, the lower portion being shaped to match the tanker-aircraft lines. The hose-drum unit, being retractable, was attached to a curved roof but rectangular top fairing prefabricated light alloy structure being pivoted at the forward end, and attached to two ball screw retraction jacks at the aft end. These were secured to a bridging structure over the rear end of the hose drum unit, and were operated by two electric driving motors in tandem attached on the rear face of the structure, as shown below, the jacks being driven via bevel gearing.



Mk XIX package mock-up, showing retraction motors

The fuel transfer system in principle was similar to that used for the Mk XVI refuelling package. However, in lieu of one PAT 30,000 fuel pump it required two to provide the fuel flow of 1,000 imperial gallons per minute. These were located at the forward end of the package's structure and were controlled in the same manner. Thence the fuel went through a venturi, fuel flowmeter, and fuel and vent shut-off valve into the hose drum. Downstream of the shut-off valve a fuel shock absorber was incorporated, providing the tanker's fuel system protection against fuel surges when the reception coupling valve closed suddenly.

Incorporated between the flowmeter and shut-off valve a ground refuelling adaptor was provided to assist in defuelling the tanker and package fuel systems.



Mk XIX package mock-up, showing fuel system

The refuelling hose bore was increased to 4 inches (106.50 mm), reducing the pressure drop for the increase in fuel flow. Thus the Mk XIX hose drum was increased in size, making the unit somewhat larger than the Mk XVI; nevertheless, the structure was designed to accept both units.

The hose-drum drive system was the same as the Mk XVI's driving motor, primary drive, fluid drive coupling and two-speed gearbox, and the braking unit was also similar.

The electronics for the complete package were located at the forward end of the package, being secured on the front face of the curved roof fairing structure. These were on one basic panel, which included a starter unit, contactor,

electronic unit for the flowmeter, and a shunt, as shown below.



Mk XIX package mock-up, showing electronics boxes

Although a very large percentage of the design work had been completed, and the package's basic fuel system for the fuel-flow rate and pressure drop across the system had been proved, the whole concept was cancelled.

CHAPTER NINETEEN

Boeing B-29 Superfortress

Receiver Aircraft

The Boeing B-29 Superfortress receiver aircraft, equipped for using the probe and drogue refuelling system, had the capability of receiving 4,416 imperial (5299 US) gallons of fuel in one refuelling from a suitably equipped tanker. The system was so designed that the two port and starboard inboard wing fuel-tanks and the rear bomb-bay fuel-tank could accept fuel in one operation. Incorporated in this system was a connection for ground pressure refuelling, thus enabling the aircraft to be rapidly refuelled on the ground.

The installation of the receiver's equipment is shown diagrammatically in [Fig 169](#) The main components were:

1. Refuelling probe assembly
2. Flight Refuelling Ltd Type Mk 7 refuelling valves
3. A scavenge fuel pump
4. Electrically operated gate valves

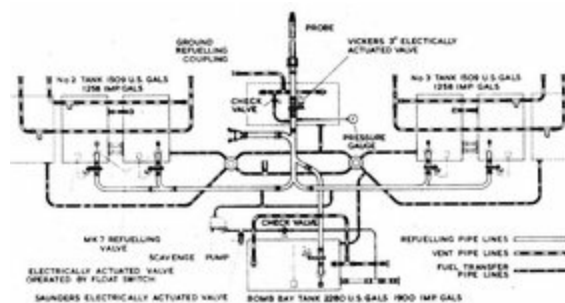


Fig. 169. Boeing B-29 Superfortress fuel system

The fuel entered the system through the 'probe' that protruded from the nose of the aircraft on the left-hand side of its centre line, and thence through the pressurized flight deck. The rear of the probe was connected by special fuel-pipe connectors to the main fuel line, which passed through the forward pressure bulkhead to the rear of the flight deck. The connectors used in this area were housed within vent boxes, which allowed any leakage of fuel to be vented from the aircraft. Aft of the pressure bulkhead the line was connected to a 3-inch electrically actuated gate valve, and thence aft to just behind the wing's main spar. In this section there were two tapplings: the first was connected by ½-inch pipe to the vent system of the forward bomb-bay fuel-tank, which included a check-valve; the second was a 3-inch pipe joined to the new ground pressure refuelling coupling fitted to the right-hand side of the fuselage between the two bomb-bay fuel-tanks.

Aft of the rear wing spar, the line was bifurcated, one branch leading directly to the rear bomb-bay fuel-tank; the other was again bifurcated, and led to each of the wing fuel-tanks through refuelling valves. The two inboard wing fuel-tanks had separate inlets, and on the inlet side of each refuelling valve an electrically actuated Whittaker shut-off valve was installed, and likewise on the inlet to the rear bomb-bay fuel-tank. These valves were installed to enable independent selection of fuel-tanks, which could be made from the aircraft's flight deck. A float-switch was fitted in each tank, and was connected electrically in circuit with the Whittaker valve installed in that particular fuel-tank; this ensured that the fuel flow would be automatically shut off in the event of a refuelling valve failure.

The fuel system, shown in [Fig 170](#), illustrates the disposition of the various components within the aircraft.

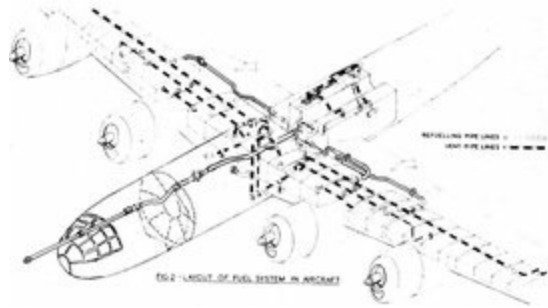


Fig. 170. Boeing B-29 Superfortress receiver, disposition of components

At the lowest position within the refuelling system, i.e. where the fuel line was bifurcated to feed the wing fuel-tanks, tapplings were made to receive connections from a scavenge fuel pump. The pump was installed within the fuselage and ensured that the in-flight-refuelling lines were scavenged of fuel after a refuelling operation. The capacity of the lines was 36 US gallons.

Fuel was drawn from the main fuel line into the scavenge box via $\frac{1}{2}$ -inch pipe, the box containing a float-switch and a pump, which pumped the fuel through an electrically actuated valve and through a check valve to the filler connection fitted to the rear bomb-bay fuel-tank. The electrically actuated valve in the outlet side of the scavenge box closed the in-flight-refuelling system from the bomb-bay tank during refuelling, thus preventing the fuel from siphoning out through the vents. The operation of the valve was automatic and was controlled by the operation of the fuel valve fitted in the probe assembly.

When the aircraft was ground refuelled, the Vickers 3-inch electrically actuated valve had to be in the closed position, preventing the probe from being pressurized. At all other times the valve had to be maintained in the open position, and was operated via a switch on the flight engineer's panel.

The probe assembly was the component through which the fuel was transferred from the tanker aircraft into the

receiver's fuel system. It was installed under the flight deck canopy to the left of the aircraft's centre line ([Fig 171](#)) and protruded 130 inches beyond its forward mounting.

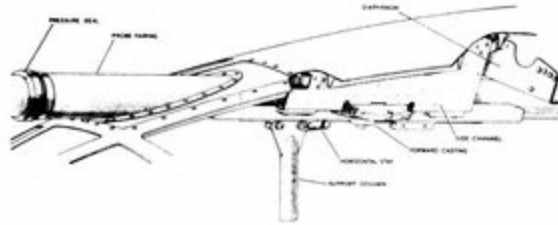


Fig. 171. Boeing B-29 Superfortress receiver, forward probe mounting

A fuel shut-off valve, which was incorporated in the probe nozzle, was actuated electropneumatically via a 24 V DC electrical supply and an air pressure of 1,500 psi.

The probe comprised four separate assemblies, which were:

1. Fuel line and probe structure
2. Probe mounting and fairing assembly
3. Nozzle assembly
4. Electropneumatic system.

The fuel line of the probe comprised two sections, one of which had piping with an outside diameter of 2.25 inches and the other 3 inches. One end of the first section was joined by a pipe connector to the rear end of the nozzle, while the other was connected to a tapered tube. The large end of the tapered tube was connected to the 3-inch pipe, which was in turn attached to the aircraft's refuelling line. Clips were fitted at 12-inch intervals along the fuel line, to provide mountings for the pneumatic piping that fed the nozzle assembly.

The probe structure acted as a stiffener for the complete probe assembly, and housed the fuel and pneumatic pipes.

The principal section of the structure consisted of a steel tube and a forward casting. The steel tube, which had a 4-inch outside diameter and was 150.70 inches in length, had a tapered steel fairing attached to its forward end. The fairing was 36 inches in length, and was internally reinforced with a threaded collar at its forward end to receive the nozzle assembly. The tube was secured to the forward mounting by two light-alloy castings, which were formed to the contour of the tube and clamped together. A split casting was also employed to secure the rear end of the tube to a fabricated box structure, which, in turn, was attached to the aircraft's fuselage. A securing flange on the end of the split casting located it on the rear of the tube.

A seal, located 7 inches aft of the joint between the fairing and steel tube, prevented air under pressure from the flight deck escaping through the annulus formed by the steel tube and the fuel line. The seal assembly consisted of a thin aluminium flange and a cylindrical alloy seal, the seal being bolted to a flange that was welded in position on the fuel pipe, and had a cut-out for the pneumatic pipes. A cork washer was interposed between the two parts, and the outside of this seal contained a groove in which a rubber seal was inserted. A sleeve positioned between the fairing joint and the end of the light-alloy seal supported the assembly, and prevented any distortion of the fuel pipe that might be caused by flight deck cabin pressure on the welded aluminium flange.

Originally the steel tube and forward mounting casting were designed for an ejector probe, and provision was made for the operating mechanism to be fitted within the casting. The probe installed for this design was a static type, but the original castings were used to provide its pick-up points.

The forward probe mounting, which comprised the two castings previously mentioned, had their jointing faces in the vertical plane. Two of the securing bolts used at the bottom joint were replaced by special attachment bolts to the end of

two horizontal stays, the other ends of which were attached to two lugs fixed to the fuselage structure at Station 63. Two bolts at the bottom joint provided the fixing for a vertical stay, and the other was pinned to a flanged base and secured to the fuselage floor.

Two fabricated light-alloy channels picked up lugs formed on each side of the castings, and these were attached at each end to side pieces that were, in turn, secured to the fuselage roof structure at Stations 63 and 81. The rear attachment was further strengthened by a light-alloy end channel and a fabricated diaphragm, the latter being attached to the existing fuselage intercostals.

The fairing was attached to the probe structure at a point where it projected through a flight-deck window in the forward pressure cabin. The window was replaced by a light-alloy cover plate, which had a large oval cut-out to allow entry of the probe structure. A 4¼-inch outside diameter tube that slid over the probe was shaped at one end to the contour of the hole in the cover plate; a flange was welded onto this end and was attached to the cover plate.

There was a further seal to prevent the escape of air from the flight-deck pressure cabin through the annulus formed by the outer probe structure. The seal comprised a machined inner sleeve riveted to one end of the outer tube, which was threaded internally. An internally threaded sleeve slid along the probe structure and was secured to the inner sleeve; a rubber seal was trapped between the mating faces of the two sleeves, and a snap ring locked them together.

The rear probe mounting comprised the box structure previously described, and picked up the lugs formed on each side of the rear split casting. There was a circular cut-out in the forward member of the fuselage roof members. The electropneumatic valve, mentioned in the probe nozzle description, was secured to the right-hand side of the box structure.

In the probe-nozzle assembly shown in Fig 172, the front portion of the nozzle was a bronze casting so shaped that when a contact was made with the reception coupling of the tanker the toggle-arm rollers within the coupling engaged an annular groove machined in the casting. The casting was externally threaded at the rear end for the attachment to a nozzle adaptor, and thence to receive the collar attached to the front of the probe structure. The adaptor had a sealing ring interposed between the nozzle casting and itself, and was beaded at the rear end for the attachment to the probe fuel line.

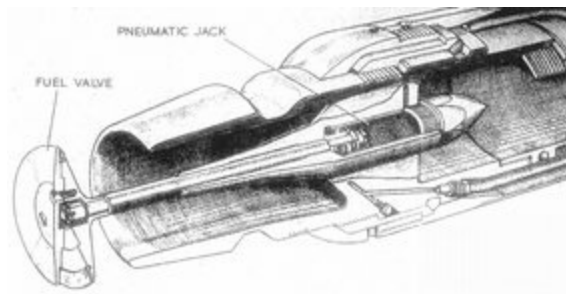


Fig. 172. Boeing B-29 Superfortress receiver aircraft, refuelling probe nozzle

A mushroom-headed valve was positioned in the front of the nozzle casting, and when in the closed position it rubber sealing ring seated on the edge of the nozzle bore. The stem of the valve was screwed to a small pneumatic ram assembly, which slid in a cylinder machined in a boss formed in the nozzle bore. The pneumatic ram assembly was sealed from the fuel by a rubber ring, and air was fed to each end of the cylinder, depending on the position of the fuel valve, through drillings in the casting that were fed by pneumatic pipes. These pipes were attached to the rear end of the nozzle casting, which, in turn, was connected to the pneumatic valve within the probe's rear structure.

The electropneumatic system contained a Dunlop control

valve that controlled the operation of the nozzle's fuel valve. The valve was connected so that when the solenoid within the valve was energized compressed air was supplied to the rear of the fuel valve's pneumatic ram, and the valve was opened. When the solenoid was de-energized, compressed air was supplied to the forward end of the ram, and the fuel valve was held in the closed position; the trapped air in the rear of the probe cylinder being exhausted into the flight-deck pressure cabin. The compressed air was supplied from the main aircraft system via a control valve located on the receiver's control panel. The operation of the pneumatic valve was controlled by a foot-switch located on the left leg of the co-pilot's instrument panel.

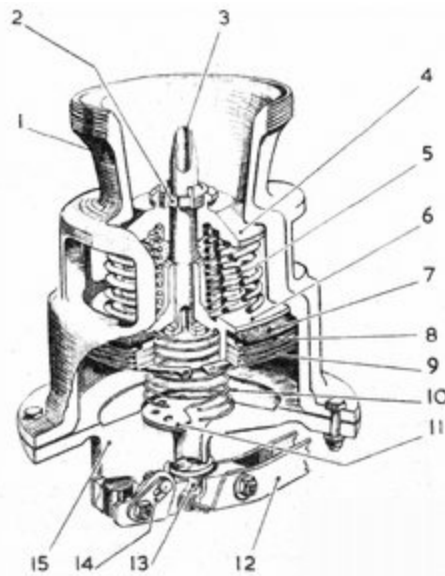


Fig. 173. Boeing B-29 Superfortress receiver, Mk 7 refuelling valve

The aircraft's new fuel system for air refuelling incorporated five Flight Refuelling Ltd Mk 7 pressure refuelling valves, as shown in [Fig 173](#). These valves were of the Series 3 type, except for the pressure-relief setting, which was modified to suit this particular installation.

The valve illustrated was a pressure-differential type, which when fitted in a fuel tank provided an automatic shut-off of the fuel supply at a predetermined level. Each valve was fitted with a flange that provided a mounting in the fuel tank, and comprised three main components—a body barrel, a piston assembly, and a float arm assembly.

The body barrel was a light-alloy cylindrical casting, one end being externally threaded to accommodate the fuel-tank adaptor. A base cap secured to a flange on the other end had a cork washer interposed, which acted as a seal between the faces of two flanges. Two steps within the bore of the barrel provided seatings for a piston crown and a piston body respectively. Four outlet ports were arranged symmetrically around the body circumference.

The piston body was fitted to the stem and retained by a shoulder at the bottom of the stem, a washer being positioned between the shoulder and the piston body. The piston crown slid on the top end of the stem, and was held away from the piston body by three relief springs, these being in compression. A split-ring retained the piston crown on the stem, a cap was screwed onto the top of the stem to seat on a split-ring and was held in position by a locking-ring.

The piston-ring assembly comprised a sealing washer, a piston-plate, shim steel piston-rings and spacing washers, which were positioned on the piston body and held against a shoulder on the body by a snap-ring.

The complete piston assembly slid into the body barrel and was loaded by a return spring so that in the static condition the piston crown and body were held on to their respective seatings within the body barrel. A light-alloy deflector plate was placed in a seating in the top of the base cap and the piston return spring seated on the plate.

The float arm of the valve comprised a valve pad mounting, self-aligning valve pad, two parallel float arms and a

varnished cork float. The valve pad mounting pivoted about a lug formed on the base cap via a pin that was retained by a key plate. The bolt that secured the key plate also located a synthetic rubber insert fitted within the valve pad mounting close to the fulcrum pin. This rubber insert restricted the movement of the float and prevented damage to it by shock loading. The self-aligned steel valve pad was screwed into the mounting so that the pad completely covered the jet orifice in the base cap when the float was in the up position. The two float arms mounted

on either side of the valve pad mounting carried at their extremities the varnished cork float.

The operation of the Mk 7 Series 3 valve was as follows:

1. In the static condition, i.e. when fuel was not flowing, the piston assembly was maintained in the closed position via a light return spring.
2. When fuel entered the valve, the piston assembly was depressed, and fuel passed into the tank through the four outlet ports. Fuel also flowed through the hollow stem of the piston into the lower chamber and out into the tank through the jet orifice in the base cap.
3. When the fuel reached a predetermined level, the rising float arm caused the valve pad to close the jet orifice, thus sealing the lower chamber from the fuel tank, and built up a pressure on the underside of the piston body assembly. Since the area of the underside of the piston body was greater than the area of the piston crown, the piston moved upwards and closed the valve.
4. As the valve closed, a shock pressure could be created in the fuel line. To prevent damage occurring to the lines by this excess pressure the piston crown was depressed against the three relief springs while the piston body remained in the closed position. Thus, the fuel was allowed to enter the fuel tank and relieve the excess pressure.

The pressure setting of the valves in this installation was 65–70 psi (4.6 bar approximately), whereas the normal Series 3 valve setting was required to relieve at 55–65 psi (4 bar).

The scavenge pump ([Fig 174](#)) was a self-priming, electrically driven pump, capable of delivering fuel at the rate of 50 imperial (60 US) gallons per hour at a pressure of 5 psi.

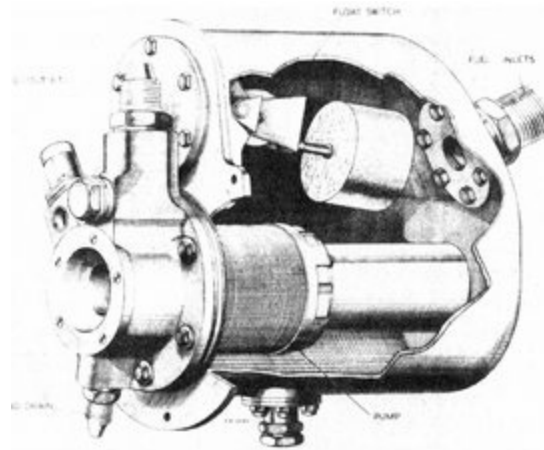


Fig. 174. Boeing B-29 Superfortress receiver, fuel scavenge box

The pump's casting had a flange at one end to secure it to the scavenge box. The other end received a port-way casting, together with the motor unit that extended into the scavenge box. The motor was encased and sealed against the ingress of fuel; the motor's shaft extended through the port-way casting and fuel sealing gland and drove the pump's impeller positioned within the chamber of the port-way casting.

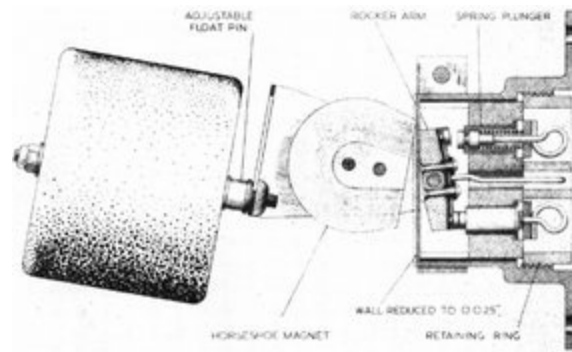
The port-way casting comprised two circular ends separated by cored-out pillars, which housed the electrical supply leads as well as providing the motor's breather-gland drain. One end housed the base of the motor unit and fuel sealing-ring, and the other end was fitted into the fuel pump's casting. This latter was formed to provide the fuel

inlet to the pump impeller, and the cored pillars were surrounded by a fine wire mesh, which acted as a filter. The pump casting was formed with a spiral volute pump chamber that led to the pump's outlet situated outside the scavenge box. Connections were also provided in the casting for the electrical supply leads and a gland drain.

The scavenge box was of welded light-alloy construction, having an oval cross-section. A strengthening plate welded on one side of the box provided an internal mounting for a float-switch and the pump. It also located the bracket for the installation of the unit in the aircraft. The fuel inlet was through a ½-inch outside diameter pipe fitting mounted on the side of the box opposite the strengthening plate; a fuel drain plug was fitted to the base of the box.

The float-switch shown in [Fig 175](#) was mounted in the upper half of the scavenge box, and controlled the operation of the pump. Thus, when the fuel reached a predetermined level in the box; the float-switch completed the pump's electrical circuit and the pump was switched on. The operation of these components was automatic, and would continue to function when the main electrical system in the aircraft was switched ON, except when the probe's fuel valve was open. When the probe fuel valve was in operation, i.e. open, the entire scavenge system was isolated electrically from the main circuit.

[Fig. 175](#). Boeing B-29 Superfortress receiver aircraft, scavenge-box float-switch



The float-switch body, which contained the electrical contacts, was a light-alloy cylinder bored to leave a wall 0.05 inches in thickness at one end. The other was flanged to provide a mounting within the scavenge box. A split clamp fitted around the body contained two diametrically opposed pins, which engaged in the side members of a float arm. A varnished cork float was attached to the float arm by an adjustable float lever. The up and down movement of the float was restricted by the poles of a small horseshoe magnet secured to the float-arm members. Thus, when the magnet was in the up or down position the poles touched the thin wall of the body, which was finally machined to 0.025 inches' thickness at the points of contact. This light-alloy screen acted as an air gap between the poles and rocker arm. The electrical contacts inside the body were mounted on the rocker arm, which pivoted in an insulated insert. When one end of the rocker was attracted to the magnet, the other depressed a spring-loaded plunger mounted within the insert, thus making an electrical circuit between a terminal connected to the rocker arm by a flexible lead and one connected to the plunger. When the magnet changed its position, by virtue of the float movement, a circuit was made between the centre of the rocker arm and a second spring-loaded plunger.

The functioning of the scavenge system has been briefly described previously. However, it is now necessary to put it into the context of an operation. The refuelling lines in the aircraft reached their lowest point after bifurcation to the

wing fuel tanks. The two ½-inch tappings were made at these positions and were connected though a tee-piece to the scavenge box via the small actuated valve and check-valve. At the end of a fuel transfer, when the foot-valve was operated, the probe fuel-valve closed, the residual fuel in the refuelling gallery was gravity fed to the scavenge box, and at the same time the small actuated valve was opened. As the box filled, the float arm of the float-switch was raised, the pump operated and forced the fuel through the check-valve into the filler-neck extension of the rear bomb-bay tank. Scavenging continued until there was insufficient fuel to support the float of the float-switch, and the falling float arm moved the rocker arm and broke the circuit to the pump.

The in-flight-refuelling control panel ([Fig 176](#)) was located on the existing wooden panel that supported the flight engineer's oxygen equipment, etc. The top of the panel contained the five warning lights and switches that controlled the Whittaker valves in the inlets to the inboard wing tanks and the rear bomb-bay tank. With the switches set to ON, the warning light indicated that the valves were OPEN; with the reverse setting OFF, they were CLOSED.

In the centre of the panel and beneath the five switches was an air-pressure gauge, which indicated the air pressure available in the pneumatic system for the probe's fuel valve (operating pressure 1,500 psi, or 102 bar).

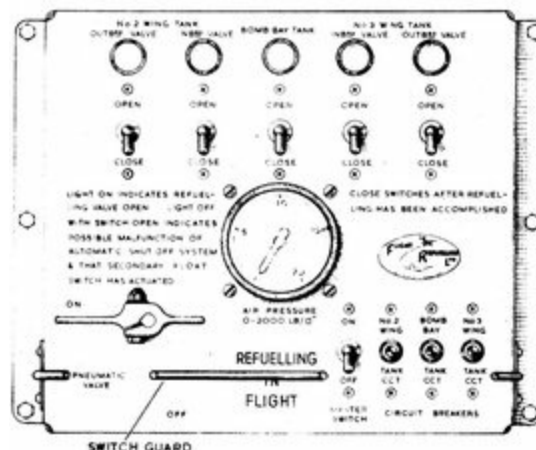


Fig. 176. Boeing B-29 Superfortress receiver control panel

The pneumatic control valve was located at the bottom left-hand corner of the panel that controlled the air supply to the probe's pneumatic valve. The right-hand corner located the electrical master switch and circuit breakers.

The electrical circuit for the installation was simple and straightforward; however, the circuit was originally designed for use with an ejector probe, but as the installation described had a static probe the fuse for this particular circuit was deleted, the intention being that the ejector probe was to be introduced later.

Immediately prior to a contact being made with a tanker, the following selections had to be made by the flight engineer:

1. Switch ON the master switch.
2. Switch ON the fuel valves, as specified by the captain.
3. Turn the pneumatic valve to the ON position and check the reading on the pressure gauge.
4. Ensure that the ground refuelling valve was OPEN. The switch for this particular valve was located on the flight engineer's panel adjacent to the fuel contents gauges.

The receiver aircraft was now ready to make a contact with the tanker aircraft.

It was important, however, that the receiver captain did not attempt a contact unless the tanker's AMBER contact light was visible. If a contact was made with no lights showing, the refuelling hose would not automatically wind in to take up the slack between the two aircraft. The hose would therefore be subject to looping. It was, however, possible that the tanker's equipment was switched on and only the contact lights were unserviceable; this had to be confirmed by R/T before a contact was attempted.

It was normally desirable to keep the probe's fuel valve

open until all fuel-tanks were full, or until the receiver had dropped back astern of the tanker so that the AMBER contact light was illuminated. If, however, it became necessary to close the probe fuel valve before the tanks were filled, or while the GREEN contact light was illuminated; a slight 'thump' might be felt within the aircraft, this being caused by the sudden shut-off of the fuel supply; but it was not harmful to the system in any way.

The flight engineer could check from the fuel-pressure gauges installed on his panel the progressive closure of the refuelling valves within the fuel-tanks. This was indicated by an increase in pressure above the running pressure until the gauges recorded the constant stall pressure of the tanker's fuel pumps.

A normal breakaway only required the receiver pilot to slowly reduce his airspeed until the probe unwound the refuelling hose to its maximum length. When the hose was fully extended (AMBER contact illuminated), or there was any further widening of the gap between the two aircraft, the probe would be pulled from the reception coupling and drogue.

The Boeing B-29 Superfortress receiver is shown below refuelling from a Boeing B-29 Superfortress tanker during trials off the Dorset coast in 1950.



*Boeing B-29 Superfortress refuelling a Boeing B-29
Superfortress, Dorset coast.*

CHAPTER TWENTY

Boeing B-29 Superfortress

High-Rate-of-Flow Receiver

The second Boeing B-29 Superfortress to be converted to a receiver aircraft differed from the previously described conversion. It was termed a 'High-Rate-of-Flow Receiver', and was designed to be used in conjunction with the Mk IX hose-drum unit installed in the Boeing B-29 three-point tanker. To achieve this higher flow rate a special progressive fuel shut-off mechanism was incorporated on the fuel shut-off valves installed within the fuel tanks.

Similar to the first B-29 receiver, the equipment installed was also designed so that the two inboard wing tanks of the starboard and port wings, together with the rear bomb-bay tank, could be refuelled in one operation. Thus 4,416 imperial (5,298 US) gallons of fuel at a high flow rate could be accepted from the tanker.

The main components of the installation were:

- A high-rate-of-flow probe assembly

- Five Mk 7 refuelling valves complete with the progressive fuel shut-off mechanism

- Scavenge box and pump unit

- Electrically actuated fuel shut-off valves

The fuel system within the aircraft was similar to the B-29 prototype receiver installation, but did not include the ground-pressure refuelling system, as shown in [Fig 177](#).

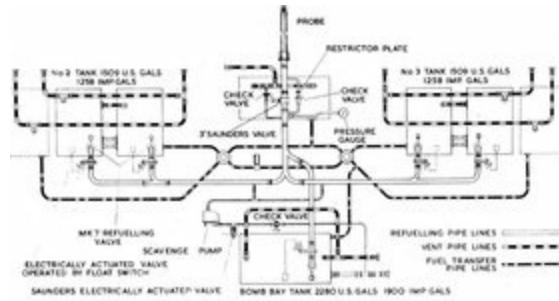


Fig. 177. Boeing B-29 Superfortress high-rate-of-flow fuel system

The disposition of the system components was also similar to the original receiver aircraft, as shown in Fig 178.

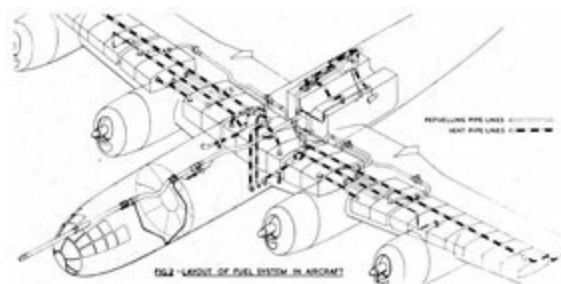


Fig. 178. High-rate-of flow receiver fuel system layout

In the original design an ejector refuelling probe was to be incorporated in the new system. In this concept the forward portion of the probe with the nozzle attached could be ejected forwards, thus assisting in making a contact. However, although the prototype assembly was installed on the Lancaster tanker G-33-1 for trials, the development of it was eventually cancelled.

The static probe protruded from the nose of the aircraft at the top left-hand side of the centre line. The rear of the probe nozzle was now connected to a 3-inch-outside-diameter fuel line, where the refuelling line passed through the flight-deck rear pressure bulkhead. Special connectors were used, and

like the first B-29 receiver were also housed within vent boxes.

Aft of the probe the line was led through a 3-inch electrically actuated Saunders fuel shut-off valve to just aft of the wing's main spar. In front of, and behind, the valve a 1¼-inch tapping was made to accommodate a part of the progressive fuel shut-off mechanism, which incorporated a check-valve and restrictor plate; the plate having a 0.825-inch-diameter hole machined in its centre. This pipe line acted as a bypass for the main fuel line. When the Saunders valve was in the closed position, the fuel passed through the bypass and was restricted by the restrictor plate, thereby reducing the fuel flow rate to 100 imperial gallons per minute. The operation of the Saunders valve was effected by the actuation of the progressive shut-off mechanism fitted to each refuelling valve, and by the operation of the flight-deck foot-switch (the latter is described elsewhere).

Aft of the rear spar the fuel line was bifurcated, one branch leading to the top of the rear bomb-bay tank and being connected via a refuelling valve, the other, which was also bifurcated, leading to each wing, where they were also connected to the inboard tanks via a refuelling valve.

The two inboard wing tanks had separate inlets, each having a Mk 7 refuelling valve with the progressive fuel shut-off mechanism. The valves were basically the same as those employed in the original B-29, operating through the fuel differential pressure. However, the progressive shut-off mechanism ([Fig 179](#)) interposed between the float and the valve's body.

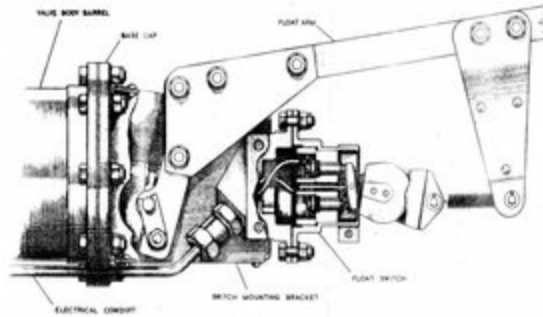


Fig. 179. Progressive fuel shut-off mechanism

The mechanism was fitted to the base cap of each of the refuelling valves and was connected electrically through a relay panel to the Saunders shut-off valve fitted in the main fuel line aft of the probe nozzle. The mechanisms were so wired that when their circuits were broken the Saunders valve was automatically closed, the supply of fuel being fed through the restrictor and bypass line, thereby reducing the fuel flow rate from 300 gallons per minute to 100 gallons, and thus preventing a high surge pressure when the Mk 7 refuelling valves were shutting off the fuel-tanks.

As the mechanism was fitted to the refuelling valve's body, two light-alloy plates were secured to the base cap of the valve on either side of the jet orifice and extended approximately 3 inches below the base cap. A block was mounted between the ends of these two plates, providing a mounting for the float, the latter replacing the valve's original float. The new float arm was also attached to a bracket at one end, and the other to a second bracket located in a mid-position on the new arm. The latter was connected to a float-switch mechanism via a small coil spring. The float-switch mechanism was the switching unit of a standard float-switch assembly secured to the body of the assembly. When the float arm commenced to rise as the fuel level within the tank increased, the small coil spring pulled the arm of the float-switch mechanism upwards, thus changing the position of the magnet. This action altered the

position of the electrical contact in the switch and broke the circuit. Thus it will be seen that as the float arm on each valve rose the electrical circuit to that valve was broken. The last valve to operate completely broke the circuit to the relay box that normally held the Saunders valve open.

Upstream of the progressive shut-off mechanism each fuel line had a Whittaker fuel shut-off valve incorporated, and to each fuel-tank float-switches were fitted, which provided an emergency circuit to the Whittaker valves in the event of a refuelling valve failure, thereby ensuring the fuel flow would be automatically shut off.

The fuel scavenge system was similar to that employed on the B-29 receiver conversion previously described. Again located at the lowest point of the refuelling fuel system, where the fuel line was bifurcated to feed the wing tanks, tappings were made to receive connections to the scavenge box and pump unit. The unit was again installed within the fuselage, thus ensuring that the fuel lines were scavenged after an operation. Similarly the capacity of the lines was the same—approximately 36 U. gallons.

Throughout the fuel system installation the fuel pipe connections were the special Flight Refuelling Ltd connectors that could withstand 150 psi (10 bar) fuel pressure. These are shown in [Fig 180](#).

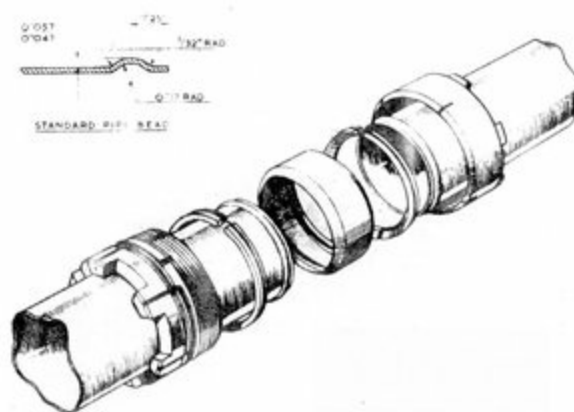


Fig. 180. Fuel pipe connectors

The electrical system illustrated in Fig 180 shows the complete electrical circuit for the high-rate-of-flow receiver. However, the overall operation of the system was the same as the original B-29 receiver system. Nevertheless, because of the higher flow rate and to prevent high fuel surges, the progressive fuel shut-off mechanism was connected electrically to the Saunders valve aft of the probe nozzle.

the current through a suppressor to the scavenge pump. The pump continued to operate until the opening of the float-switch stopped it by de-energizing Relay 3. The actuated valve circuit remained energized to OPEN.

When a refuelling operation was about to commence, and the master switch was closed, current passed from Fuse 3 to Terminal Block 7, then to the

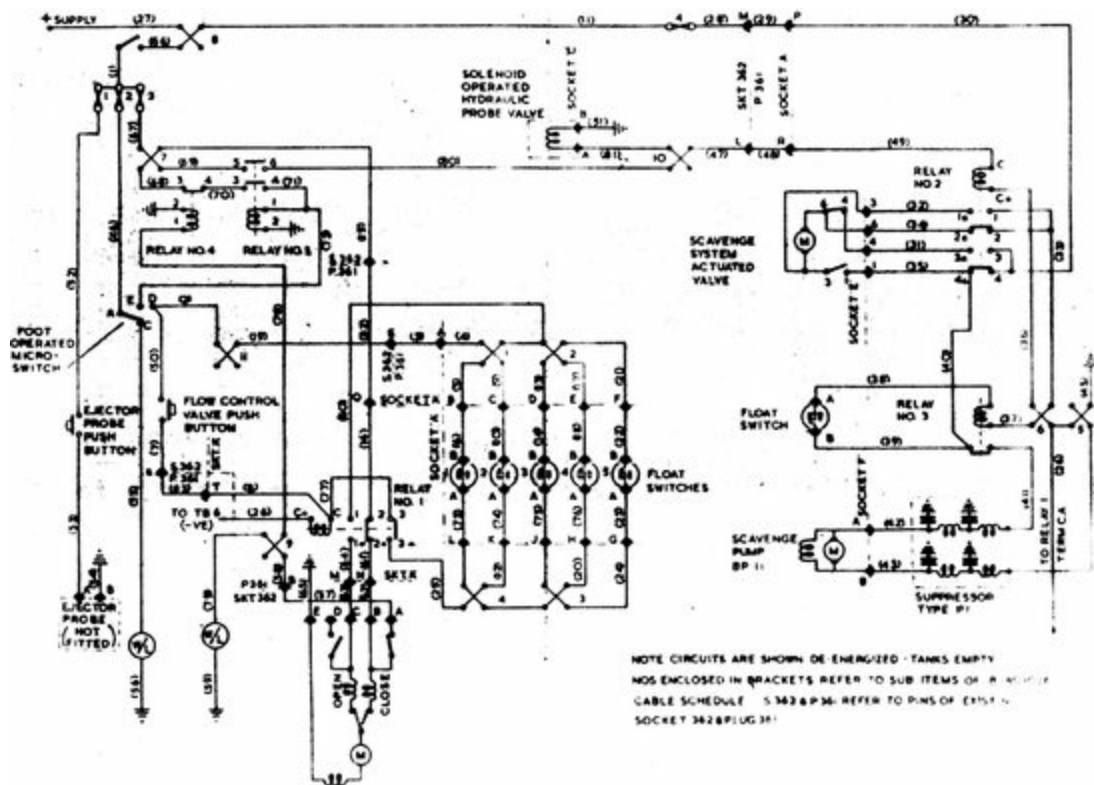


Fig. 181. Boeing B-29 high-rate-of-flow electrical circuit

As previously mentioned, in the original design an ejector probe was to be incorporated, and so the electrical diagram illustrates the wiring and switch that would have been required.

Irrespective of the position of the master switch, current passed from the aircraft's electrical supply by way of Fuse 4 through a normally closed pair of contacts of Relay 2, to a contact of the normally opened Relay 3 to the rotary actuator in the scavenge box.

When the float-switch within the box closed, the current was passed to the operating coil of the normally opened Relay 3, which closed and passed first of the normally opened contacts of Relay 5, and to the second of the normally opened contacts of Relay 5 via the normally closed contacts of Relay 4. Terminal Block 7 was also connected through a normally closed pair of contacts on Relay 1 to the closed field of the 3-inch Saunders valve at the rear of the probe, and through the indicator-switch on the valve's Terminal Block 9, turning on the AMBER contact light on the co-pilot's panel and energizing Relay 4 (referred to above), and so disconnecting Terminal Block 7 from the second pair of contacts of Relay 5.

Current was supplied from Fuse 2 to the foot-switch, and when in the OFF position current was passed through its normally closed contacts to an indicator light.

Fuse 1 supplied current to a push-button for the operation of the ejector probe, though this was not fitted in the original conversion.

When the receiver had made a contact with the tanker, the foot-switch was first depressed. The change-over extinguished the indicator light and passed the current to Terminal Blocks 1 and 2, and to the operating coil of Relay 5, which then closed and passed current to Terminal Block 10,

thereby opening the probe's fuel valve and energizing Relay 2, which changed over and disconnected the scavenge pump, and at the same time closed the small actuated valve. From Terminal Blocks 1 and 2, current passed through the fuel-tank float-switches, all of which were connected in parallel to Terminal Blocks 3 and 4, and then to the normally opened pair of contacts on Relay 1. Another line from Terminal Blocks 3 and 4 were connected directly to the other opened contact of Relay 1.

The 3-inch Saunders valve press-button was then depressed, and the current now passed to the operating coil of Relay 1, which changed over and disconnected the 'closed' field and connected the 'open' field of the valve's actuator, opening the valve, at the same time extinguishing the AMBER contact light on the co-pilot's panel. The operating coil of the relay was connected by the closed contacts to the line from the float-switches, and as long as one or more of these remained closed the relay was held operated after the press-button was released.

As the fuel-tanks filled, the last float-switch to operate and open its contact disconnected the holdin supply, and Relay 1 opened and changed over its contact, thus disconnecting the 'open' and connecting the 'closed' field of the Saunders valve, which then closed. When closed the back contacts of its limit-switch illuminated the AMBER light on the co-pilot's panel and energized Relay 4. When the foot-switch was released, Relay 5 was de-energized. The supplies to Relay 1 were direct, and through the float-switches they were disconnected and the probe valve was closed because Relay 2 was de-energized. The disconnection of this supply opened the scavenge pump's small actuated valve and connected the float-switch to operate the pump as necessary.

If the foot-switch was released before the 3-inch Saunders valve was fully opened, Relay 5 was held closed by a supply from Terminal Block 7 through the closed contact of Relay 4 to those of No. 5, to hold it closed. When the valve's limit-

switch was closed, Relay 4 was energized, and because this circuit was now broken Relay 5 opened and the probe's fuel valve was de-energized and thus closed.

In this conversion it is unnecessary to describe the probe nozzle and the probe structure, together with its installation, as it was similar to that of the original B-29 receiver and its operation. Likewise the control panel that controlled the fuel transfer system within the aircraft, which also was located at the same position and operated in the same manner.

CHAPTER TWENTY-ONE

Republic F-84E

Thunderjet Receiver Aircraft

The Republic F-84 Thunderjet receiver was capable of having all its fuel-tanks replenished in a single refuelling operation. Thus a total of 759 imperial (912 US) gallons could be transferred.

The refuelling probe on the Republic F-84 Thunderjet protruded from the leading edge of the aircraft's port wing, as illustrated in [Fig 182](#), which also shows the disposition of the various components and fuel lines.

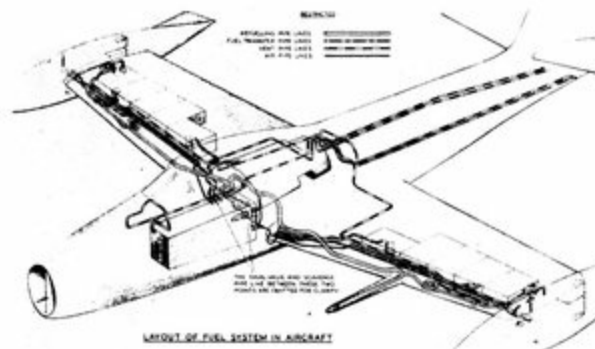


Fig. 182. Republic F-84 receiver aircraft

The fuel entered the aircraft's fuel system through the probe, which was attached to the forward face of the forward wing-spar; the rear of the probe being connected to a 2¼-inch outside diameter fuel line, which was bifurcated. One branch of the bifurcation turned through 90 degrees,

and was reduced to 2 inches outside diameter. It was then led along the port wing's leading edge through the fuselage to a position half-way along the starboard wing's leading edge. At this position the line was reduced to 1¾ inches outside diameter, and after a further 4-foot run in length was again reduced to 1¼ inches outside diameter where it was connected to a Saunders-type electrically actuated shut-off valve. From the outlet of the valve the fuel was tapped into the existing 1-inch outside diameter line that fed the starboard wingtip fuel-tank.

The other branch of the bifurcation at the rear of the probe was made with a 1¼-inch outside diameter line, which was led along the port wing's leading edge to a second Saunders-type electrically actuated shut-off valve, and positioned close to the port wingtip fuel-tank. The outlet of this valve was connected to the tank in a similar manner to that of the starboard tank.

In Fig 183 the complete fuel system is shown diagrammatically, and the two fuel lines previously described were the main fuel replenishment lines of the in-flight-refuelling system. The two Saunders-type valves were operated through float-switches fitted in the tanks. Also, as these tanks were interchangeable port with starboard, they were fitted with two switches; it was only necessary to change the external connections when a tank change was made.

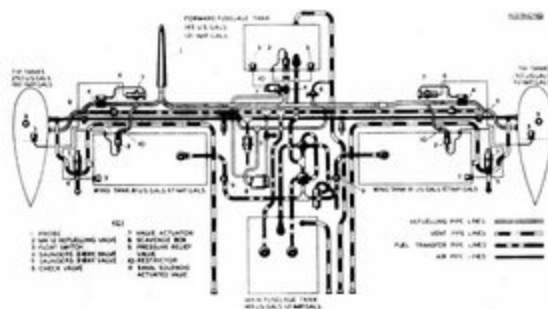
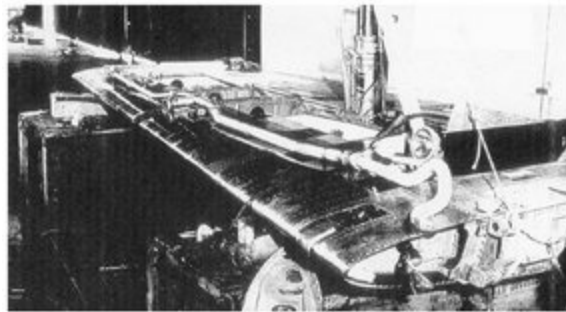


Fig. 183. Republic F-84 Thunderjet receiver fuel system

The photograph below shows the port wing of the aircraft is shown during the conversion into a receiver aircraft.



Republic F-84 Thunderjet wing conversion

The main refuelling line from the probe to either end of the wing has been laid on the outer wing skin to indicate its run.

Inboard of the port and starboard Saunders valves, tappings were made in the fuel line to feed the port and starboard wing tanks. The lines were $\frac{3}{4}$ inch outside diameter and were fitted with restrictor plates, the apertures of which were 0.45 and 0.43 inches respectively. The fuel lines were connected to the tanks by a flanged adaptor, which also provided a mounting for the Mk 12 Flight Refuelling Ltd refilling valve. These valves were electrically operated by the float-switches installed within the fuel-tanks. A further tapping was made in the main fuel line where it passed through the fuselage, and was connected to a $1\frac{1}{4}$ -inch outside diameter line that fed the forward auxiliary fuel-tank. An electrically actuated Saunders-type valve and a line restrictor of 0.635-inch diameter were fitted in the line.

Owing to the reduction in fuel line diameters, together with the restrictors, the fuel flow rate to the wingtip fuel-tanks and the forward fuselage tank were controlled. This ensured that the rate of fuel transferred to each individual tank, including the main fuselage tank, which was fed by the

aircraft's internal system, was such that all tanks were filled at approximately the same time. Thus, it was possible to refuel all tanks in the aircraft in a single operation at a higher rate than would have been otherwise possible.

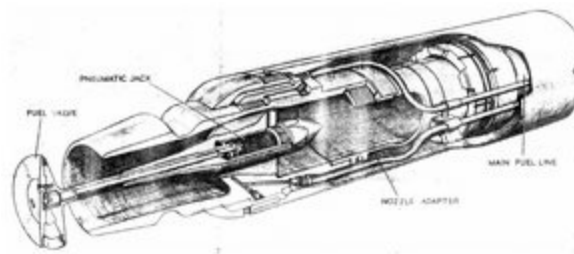
At the lowest point in the converted fuel system, i.e. in the fuselage, tapings were made in the main fuel line to receive connections from a scavenge fuel-pump unit. The unit was installed in the fuselage and ensured that the in-flight-refuelling lines were scavenged of fuel after the operation. The outlet from the scavenge pump unit was connected to the wingtip fuel transfer line that fed the main fuselage tank. An electrically actuated valve was fitted in this line to prevent the fuel transfer line from being pressurized during an operation. A check-valve was fitted in a ½-inch outside diameter line connecting the main fuel line to the vent system, which permitted the entry of air as the system was scavenged.

The vent system of the aircraft was modified to incorporate the in-flight-refuelling equipment, and a 1¼-inch Saunders-type three-way actuated valve was installed alongside each wingtip tank. The vents from these and the aircraft's wing tanks were connected to the Saunders valve. When the master switch was set to ON, the vent was open to the atmosphere; when the switch was set to OFF (normal flight conditions), the wing tanks remained vented through the existing vent line, but the wingtip tanks were sealed. The existing air line, which was used to pressurize the wingtip tanks for internal fuel transfer, was teed into the vent system so that when the Saunders valve was OFF, this method of fuel transfer was still operative. A suction-relief and pressure-relief valve were fitted in each wingtip tank; the former allowed air to enter the tank during a change of altitude, and the latter prevented a build up of pressure within the tank of over 70 psi.

Safety devices were incorporated in the system for use in the event of the failure of the normal shut-off system within

the tanks. The Saunders electrically actuated valve on the inlet of the forward fuselage tank prevented damage to the tank from overfilling, while the increase in the venting capacity prevented damage to the wing tanks from a similar cause. To allow for a failure of the shut-off system in the wingtip tanks, an additional relief valve was fitted. This valve relieved at the same pressure as the relief valve previously mentioned, but had the additional advantage that it allowed a leak of up to 67 imperial (80 US) gallons per minute without any increase in internal pressure.

The probe assembly ([Fig 184](#)) was installed in the port wing on a special mounting bracket, fitted to the forward face of the sub-spar, and protruded a distance of 4 feet 6 inches (1,371 mm) from the wing's leading edge. The assembly comprised a cast mounting bracket, a fuel line, the probe structure and a nozzle assembly. Incorporated within the nozzle was a fuel valve, which was electrohydraulically operated.



[Fig. 184](#). Republic F-84E Thunderjet probe

The mounting bracket, which was of a box construction manufactured in light alloy, was fitted in the leading edge of the port wing. The forward end of the bracket was machined to form a hollow boss that provided the mounting for the probe structure. The wing structure was modified to receive the bracket, and the wing rib at Station 126.0 was removed and replaced with a stiffer rib at Station 125.812, to which the right-hand side of the bracket was secured. The wing rib

at Station 130.5 was cut away forward of the sub-spar, and a new nose rib was fitted at Station 131.812, the left-hand side of the bracket being secured to it. The rear of the bracket fitted against the front face of the sub-spar, which was stiffened to receive the securing bolts. A detachable panel was fitted to the underside of the bracket to provide an access to the fuel and hydraulic connections to the probe. This was 50.8 inches in length, beaded at each end of the probe fuel line to receive a special pipe connector. Four clips were fitted at intervals along the piping, providing the mounting for the hydraulic pipes that fed the nozzle assembly.

The probe structure, a tapered light-alloy tube, acted as a stiffener for the complete probe assembly and housed the fuel and hydraulic pipe lines. One end of the structure was fixed over the cast mounting bracket and was secured by retaining screws. The other had an internally threaded collar riveted in position, providing a mounting for the nozzle assembly.

The probe nozzle assembly was similar to that employed on the Boeing B-29 Superfortress receiver aircraft, and differed only in that the mushroom-headed fuel valve was operated electrohydraulically. The valve's stem was screwed to a small hydraulic piston assembly that slid in the cylinder machined within the boss formed in the nozzle's bore. The hydraulic piston was sealed from the fuel supply by a rubber ring, the hydraulic oil being fed via hydraulic pipes.

The hydraulic supply for the valve operation was taken from the main hydraulic system of the aircraft. Tappings were made from this system aft of the cockpit. A Dowty electrohydraulic control valve was incorporated in the pipe lines, which were then fed along the port wing leading edge to the probe assembly.

The control valve contained two solenoids that controlled the oil flow through the valve. These solenoids were

connected through the cockpit master switch, and a bomb-release button, which was located on the aircraft's control column. When the master switch was set to OFF the two solenoids were de-energized and both inlet and outlet of the valve were CLOSED. Thus the fuel valve was hydraulically locked in the closed position. Immediately the master switch set to ON, one of the solenoids was energized and opened the valve that supplied hydraulic pressure to the forward end of the probe's cylinder, thus maintaining the fuel valve in the CLOSED position. If the bomb-release button was depressed while the master switch was set to ON, the first solenoid was de-energized, and the second energized, thus allowing the hydraulic pressure to be fed to the rear of the cylinder and therefore opening the valve.

The control valve had incorporated in it a thermal relief valve so that when the master switch was set to OFF, and the probe's fuel valve was hydraulically locked, any increase in pressure within the locked lines due to temperature change would be relieved, thus preventing damage to the piping.

The electrical circuit for the installation is shown in [Fig 185](#) The main positive feed to the circuit was taken from the fuel and starter relay box, which was positioned on the starboard side of the aircraft's centre section. It was then led to a main fuse box installed on the bulkhead aft of the auxiliary fuel-tank. The fuse box contained eighteen numbered fuses, two of which were not utilized in the circuit.

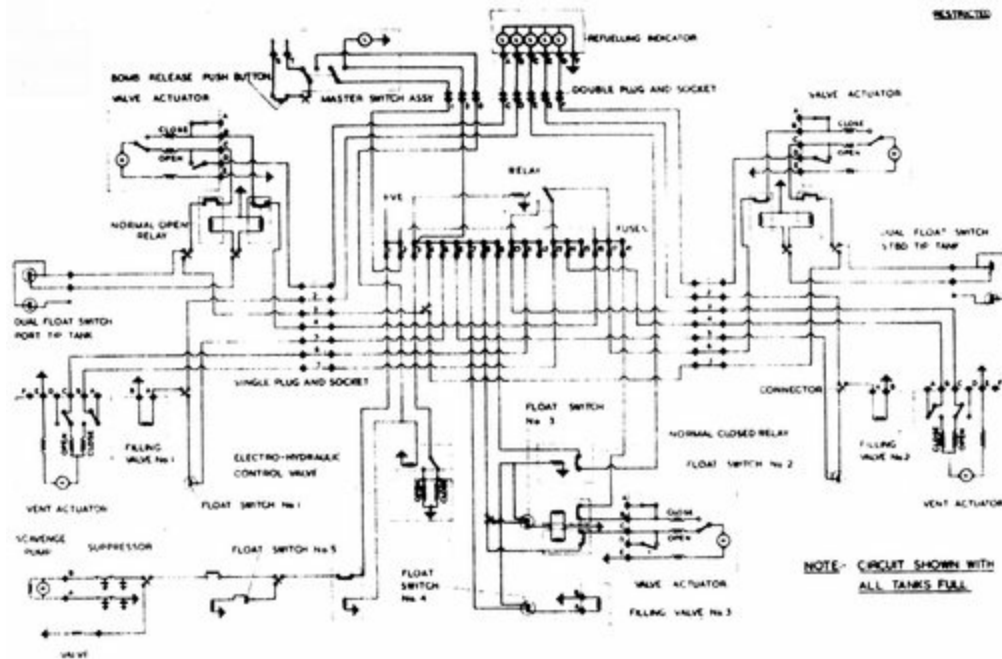


Fig. 185. Republic F-84E Thunderjet receiver electrical circuit

The following description takes each fuse in turn and briefly describes its individual circuit.

- | | |
|-----------|---|
| FUSE
1 | Input directly from main aircraft supply. Output via a relay to float switch fitted in the scavenge box, and then to the radio noise filter. |
| FUSE
2 | Input from input of Fuse 1. Output to one side of the master switch in the cockpit. The input side of the fuse also fed Fuses 16, 17 and 18. |
| FUSE
3 | Input, which was common to Fuses 3 to 9 inclusive, was from the other side of the master switch, and also connected to the coil of Change-over Relay No 2 for the operation of the vent valves. The output was to Change-over Relay No. 1, and to the electrohydraulic control valve that |

controlled the supply of hydraulic pressure to the probe's fuel valve. The coil of Change-over Relay No 1 was energized when the bombrelease button on the control column was depressed. The relay in the scavenge, thus isolating the scavenge unit.

FUSE 4 Output was via Terminal Block FR1 to Terminal Block FR6, which supplied Relay No. 4 in the starboard wing, and the wingtip float-switch. From the float-switch a lead was taken to Terminal Block FR5, which would energize the coils of Relays 3 and 4. Relay 3 was energized by the output from Fuse 17. This paragraph also applied to the port wing through Relays 1 and 2, Terminal Blocks FR3 and 4.

FUSE 5 Output to Float-Switch No. 1 installed in the port wing tank, via Terminal Block FR2, to the Mk 12 Refuelling Valve No. 1 installed in the same tank. The output also led to the refuelling indicator installed in the cockpit.

FUSE 6 Output to Float-Switch No. 3 installed in the starboard wing tank, via Terminal Block FR7 to the Mk 12 Refuelling Valve No. 2. The output also led to the refuelling indicator installed in the cockpit.

FUSE 7 Output was to one side of Float-Switch No. 4 installed in the forward fuselage tank. On the other side, one lead fed the coil of Relay 5, and a second lead fed the Mk 12 Refuelling Valve No. 3 fitted in the same tank.

FUSE 8 Output was via Terminal Block FR8 to Float-Switch No. 3 installed in the forward auxiliary tank. On the other side of the switch were two

leads, one to the coils of Relays 6 and 7, the other to the coil of Relay 5. A second lead was taken from Terminal Block FR8 to supply Relay No. 6, and then to the actuator for the operation of the Saunders valve in the forward Fuselage tank inlet.

FUSE 9	Output to Relay 5, and then to refuelling indicator.
FUSES 10, 11	Input supplied from Change-over Relay No. 2. Output from Fuse 10 to vent actuator in starboard wing. Output from Fuse 11 to vent actuator in port wing tank.
FUSES 13, 14	Input supplied by Change-over Relay No. 2. Output from Fuse 13 to vent actuator in starboard wing. Output from Fuse 14 to vent actuator in port wing.
FUSES 16, 17	Input supplied from input side of Fuse 2. Output of Fuse 16 was to Relay No. 1 and on Saunders valve situated in starboard wing.
FUSE 18	Output was to Relay No. 7 and to Saunders valve situated on inlet of forward fuselage tank.

The Republic F-84E Thunderjet receiver installation had three Mk 12 Flight Refuelling Ltd pressure refuelling valves incorporated in the system. While the principle of the operation was identical with the standard Mk 12 Series 2, certain modifications were introduced to adapt them to this particular installation. Where a deviation was made from the Series 2, the modified version is described.

The Mk 12 pressure refuelling valve ([Fig 186](#)) was electrically operated, and a differential-pressure-type valve,

which when used in conjunction with a float-switch and fitted within a fuel tank provided an automatic shut-off of the fuel supply at a predetermined level. Each valve was fitted with a flanged adaptor providing a mounting for the valve. It comprised three main components: a body barrel, a piston assembly and a solenoid assembly. The body barrel was a light-alloy casting which had a flange adaptor plate screwed on one end, and a base cap with a jet orifice in its centre screwed to the other end. The base cap was secured in position by a locking ring, and two steps were machined in the bore of the barrel to provide seatings for a piston crown and piston body respectively. Four outlet ports were arranged around the body's circumference.

The piston comprised the hollow stem of the piston crown, which slid in a steel liner fitted in the bore of the piston body, the piston crown being held away from the body by two coil relief springs. The stem of the crown was machined at its base to receive a conical sealing washer and two split collets, which were fitted in position when the piston stem protruded through the underside of the piston body, and the relief springs in compression. The collets were retained in position by a hollow cap, which in turn was secured to the stem by a snap-ring.

The piston ring assembly comprised a synthetic rubber sealing washer, a piston ring plate, three shim steel piston rings and two spacers, together with a piston ring retaining plate.

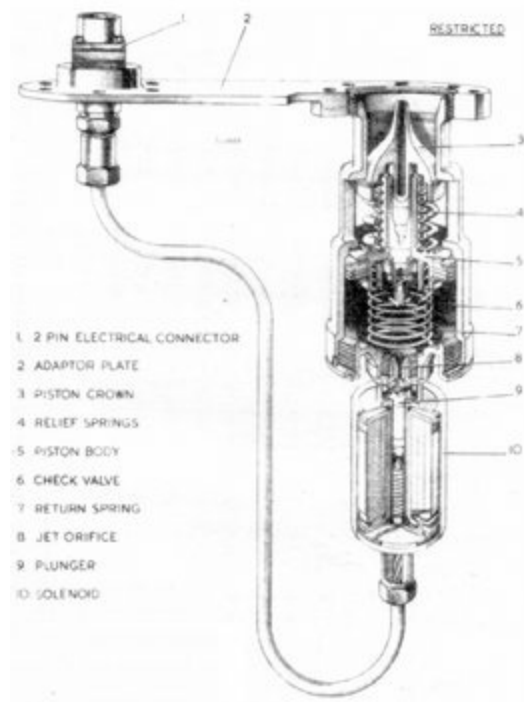


Fig 186. Republic F-84E Thunderjet receiver Mk 12 refuelling valve

The piston ring plate was stepped on its outer edge to enable the rubber sealing ring washer to flex when it contacted the sealing face within the body barrel. The piston ring assembly fitted on the piston body and was retained in position by a snap-ring.

The complete piston assembly slid in the body barrel, and was retained in the closed position by a light coil spring fitted between the underside of the piston body and the valve base cap. A flanged end of a check-valve housing was interposed between the end of the piston return spring and the underside of the piston body.

A rubber-seated valve, which slid in the housing, was spring loaded, and bore against the orifice in the piston stem. This check-valve prevented fuel siphoning through the piston assembly.

Each of the Mk 12 valves in the installation contained a

solenoid assembly similar to that fitted to the Mk 12 Series 1 valve.

A copper-plated case that contained the solenoid had a port housing brazed on one end. This housing had four ports spaced equally around its circumference, and was threaded internally to receive a valve seat. An external thread on the opposite end allowed it to be screwed into the centre of the valve's base cap. Through the centre of the valve seat there was an orifice leading directly to the four outlet ports, which was normally blanked off by a spring-loaded plunger. This plunger slid in a liner inserted in the centre of a bobbin on which was wound the solenoid's coil. When the coil was energized, the plunger was pulled back onto a conical seat fixed within the bore of the bobbin. A hole through the centre of the plunger allowed trapped air to escape through the ports. Two wires, which supplied the electrical current to the solenoid, were carried in a light-alloy conduit from the end cap attached to the solenoid case to the flanged adaptor on the wall of the fuel-tank.

The electrical supply to the solenoid was led through a float-switch installed within the same fuel-tank as the valve. The float-switch is therefore treated as one unit when considering the functioning of the valve.

1. In the static condition, i.e. when the fuel was not flowing and the solenoid was not energized, the piston of the valve was maintained in the CLOSED position via the light return spring.
2. Before fuel could enter the tank through the valve the solenoid had to be energized by switching ON the in-flight-refuelling master switch. As fuel entered the valve, the piston was depressed, and the fuel passed into the tank through the four port outlets. Fuel also flowed through the hollow piston stem and check-valve into the lower chamber, and out into the tank through the solenoid's ports.
3. When the fuel reached a predetermined level, the rising

float-arm on the float-switch broke the continuity of the electrical circuit to the solenoid. Since the solenoid was no longer energized, the plunger blanked off the orifice in the valve seat, thus sealing the lower chamber and building up a pressure on the underside of the piston assembly. As the area of the underside of the piston body was greater than that of the crown, the piston assembly moved upwards and closed the valve.

4. As the valve closed off, a shock pressure could be created in the fuel line. To prevent damage to the line by the excess pressure, the piston crown was depressed against the two relief springs, while the piston remained in the closed position. Thus, fuel was allowed to enter the tank and relieve the pressure within the fuel.

The pressure relief setting of these valves was similar to that of the Mk 12 Series 2, which was between 55 and 65 psi.

The scavenge box and pump unit was the same as that employed on the Boeing B-29 Superfortress receiver, and likewise the float-switches and fuel-pipe connectors.

As the Republic F-84E Thunderjet was the first single-seat jet fighter to be introduced into service, it was essential that a detailed flight procedure was laid down prior to a service pilot making a refuelling contact.

Before the precontact procedure (given below) was carried out, the receiver pilot had to set his fuel selection to ALL-TANKS, and switch the wingtip tank's pressurization to OFF. The in-flight-refuelling master switch was then set to ON. When this selection had been made, the indicator box containing the five warning lights would indicate which tanks required fuel. On these actions being completed, the following was then adopted:

1. When the receiver pilot was approximate one mile astern of the tanker aircraft, the pilot reduced his airspeed to approximately 50 mph faster than the tanker's speed.
2. On completion of the above action, the receiver pilot

then applied his air brake to open.

3. The receiver pilot then closed to about one-quarter of a mile astern of the tanker, and lowered his flaps and retracted the air brake. He then continued to close the gap between himself and the tanker until he was 40-50 yards behind.

The receiver pilot was now ready for making a contact. It was important to note, however, that the receiver pilot must not attempt to make a contact unless the tanker's AMBER warning light was visible.

When the receiver pilot had carried out this procedure and taken the precautions observed, he had to concentrate his attention on the tanker's drogue and the probe nozzle. It was important in making a contact that the receiver pilot **MUST** fly the probe directly into the reception coupling and drogue, and at all times avoid hesitating a few feet behind the drogue and then 'chasing' it. If for some reason the pilot hesitated on the run in, it was advisable to drop back 5-10 yards, and commence a new run.

Once a contact had been made, the pilot must continue to close the gap between the two aircraft until the indicator lights (later to be called contact lights) changed from AMBER to GREEN. The bomb-release button must then be depressed and the fuel transfer would commence. If, during the transfer, the GREEN indicator light changed to AMBER, the receiver was too far from the tanker and the fuel transfer would automatically cease.

On completing the operation it was normally desirable to keep the probe fuel valve open until all five warning lights were extinguished, indicating that all tanks were full, or until the receiver had dropped astern of the tanker so that the AMBER indicator light was illuminated. If, however, it became necessary to close the fuel valve before all the five indicator lights in the receiver were extinguished, a slight thump would be felt throughout the aircraft. This was

caused by the sudden 'cut-off ' of the fuel flow and had no adverse affect on the equipment or system.

When the required quantity of fuel had been transferred, or at any time during the operation, the receiver pilot could break contact by reducing his airspeed and pulling the probe from the reception coupling and drogue. It was important in this event, however, that before he broke contact the bomb-release button had to be depressed to avoid splashing fuel. In a normal break-away the pilot would slowly reduce the airspeed until the probe had unwound the refuelling hose to its maximum length. When the hose was in the fully extended position (AMBER indicator light illuminated), any further widening of the gap between the two aircraft would pull the probe from the reception coupling and drogue. After the contact had been broken the receiver pilot had to switch OFF the master switch and raise the flaps.

CHAPTER TWENTY-TWO

Mk 20 Under-wing

Air Refuelling Pods

The Mk 20 prototype under-wing refuelling pod was derived from a visit by Sir Alan Cobham to Flight Refuelling Incorporated to see what progress had been made with the American 'Buddy-Buddy' system. This was being developed for the American Navy by Douglas Aircraft as an under-wing refuelling pack; also, it was intended for use on bomber aircraft. The concept was where a hose-drum unit and a power source were incorporated in an under-wing drop-tank, capable of being fitted to various types of aircraft as a standard fit, the parent aircraft being capable of either dispensing fuel to a receiver aircraft, or using the fuel within the tank for its own purpose, and able to be replenished during a refuelling operation.

The pod comprised three compartments: the power unit, fuel tank and hose-drum unit enclosed in a rear fairing.

Mk 20 prototype refuelling pod



Control of the equipment within the pod was exercised jointly through switchgear fitted in the pod, and through switches contained in a small control panel located in the cockpit of the tanker. In addition to the switches, the control panel carried certain lamps that provided immediate visual evidence regarding the progress of the refuelling operation.

The prototype of the Mk 20 series of refuelling pods was flight tested on Canberra WK143, this particular pod having what was termed a 'bluff end' to house a ventilated drogue similar to that used on the Valiant tanker. There were eventually six variants of the pod designed and manufactured, and a further two were proposals that did not come to fruition.

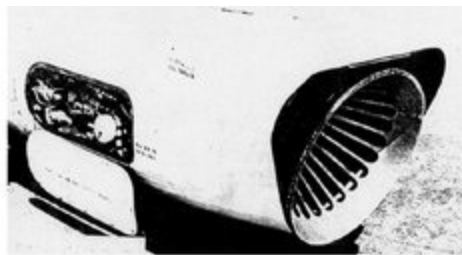
These are described under their separate headings in later paragraphs, but a brief description is given here as to which aircraft they were either proposed for or actually installed in.

- | | |
|-----------|---|
| 1. Mk 20 | Prototype pod with bluff end housing a metal ventilated drogue. |
| 2. Mk 20A | Production version for use on Vickers Armstrong Scimitar and de Havilland Sea Vixen. Streamlined rear fairing using a collapsible drogue. |
| 3. Mk 20B | Variant of Mk 20A, making the pod interchangeable with the Handley Page Victor Mks 1 and 2 tankers. |
| 4. Mk 20C | Further variant of Mk 20A, making pod interchangeable with Vickers Armstrong Scimitar, de Havilland Sea Vixen and Blackburn Buccaneer. |
| 5. Mk 20D | Further variant of the Mk 20C, with offset |

rear fairing to suit installation on the Armstrong Whitworth Argosy. Only one type produced for flight trials.

- 6. Mk 20E Modified version of Mk 20C and Mk 20B, permitting total interchangeability between Vickers Armstrong Scimitar, de Havilland Sea Vixen, Blackburn Buccaneer, and Handley Page Victor B Mks I and 2. Three-point tankers.
- 7. Mk 20.F Variant of Mk 20E, having larger- capacity fuel-tank and an additional booster pump, proposed for the French naval Jaguar.
- 8 Mk 20G Variant of Mk 20B, with extra soleplate mounting for fuselage attachment to MRCA Tornado.

The prototype Mk 20 differed from the production Mk 20A in that it had the bluff end rear fairing to house the rigid metal ventilated drogue. Though smaller in diameter it was similar to that employed on the Valiant tanker, as shown below.



Mk 20 bluff rear-end fairing, showing drogue

The MK 20A, however, incorporated a streamlined rear fairing, which housed the later collapsible drogue, as shown below.



Mk 20A streamlined rear fairing

Also, the early Mk 20, Mk 20A and Mk 20C used a ten-bladed constant-speed Dowty Rotol Ltd ram air turbine, which provided 30 horsepower to drive the pod's fuel-transfer pump and hydraulic pump, the latter providing the necessary power for the operation of the hose-drum unit. As the ten-bladed turbine was only in use for a short period of time, an in-depth description has not been included; nevertheless it was a part of the pod's development in the original design. A two-bladed Dowty Rotol feathering turbine, shown below, was introduced, which provided the same power, and was capable of feathering the blades, which reduced wear during its operation.



Mk 20 ten-bladed ram air turbine



Mk 20A two-bladed ram air turbine

The leading particulars for the Mk 20 production series of refuelling pods were:

All-up weight (150 gallons of fuel in tank)	2,050 lb
Net weight (dry)	925 lb
Capacity of fuel tank	145 imp gal (652 litres)
Fuel transfer flow rate	150 imp gal (675 litres) per minute
Fuel jettison flow rate Fuel pressure at reception coupling	85 imp gal (382 litres) per minute 50 psi (3.4 bar)

Speed of two-bladed ram air turbine:

Blades at fine pitch	7,750 rpm during refuelling 9,000
----------------------	-----------------------------------

	rpm maximum transient overshoot.
Blades at coarse pitch, feathered	2,800 rpm maximum (estd) at 500 K EAS, 14,500 feet altitude,
Length of refuelling hose	50 feet
Bore of refuelling hose	1.5 inches
Hose normal 'wind' speed	1.64 feet/second
Operational 'wind' response	12 feet/second
Normal hose 'trail' speed	3 feet/second
Emergency 'trail' speed	5-6 feet/second
Overall length of pod	13 feet 6 inches
Diameter of pod	2 feet 4 inches

The Mk 20A refuelling pod is shown below, and it was from this standard that all the other derivatives were derived.

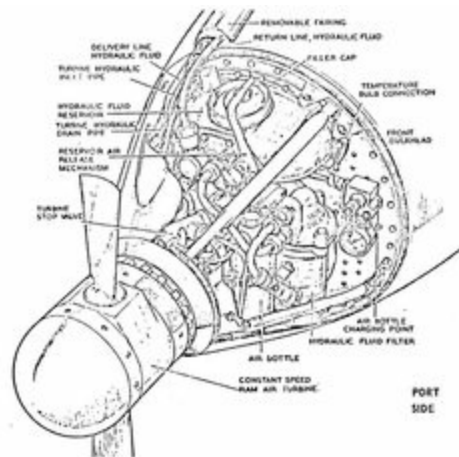


Mk 20A refuelling pod

The pod assembly consisted of the three main compartments, at the forward section the power unit assembly, the centre section the fuel-tank and the rear section the hose-drum unit complete with a rear fairing, the disposition of which is shown in [Fig 187](#).

The power unit ([Fig 188](#)), located at the forward end of the pod was mounted to the forward structure of the fuel-tank. Originally the prototype had the ten-bladed, constant-speed ram air turbine; however, the Mk 20A had the two-bladed ram air turbine providing the necessary power of 30 h.p. at 7,750 rpm

during the refuelling operation. This necessitated modifications to the power-unit gearbox to provide hydraulic pressure to the turbine blades for blade pitch change, as shown in the hydraulic diagram.



[Fig. 188](#). Mk 20A power unit

It was attached to a self-contained reduction gearbox, the turbine's rotary drive was taken through a quill shaft driving the reduction gearbox to a PR 9000 fuel

pump (initially designed by Pulsometer Ltd, later by SPE

Ltd, and lastly by the Plessey Company), a gearbox lubrication pump, and a Vickers Sperry Rand hydraulic pump.

The fuel pump was designed to deliver 150 imperial gallons (675 litres), at a pressure rise of 106 psi (7.20 bar) at 4,000 rpm. The Vickers Sperry Rand hydraulic pump provided a nominal fluid flow rate of 1.94 imperial gallons (8.7 litres) per minute at 3,500 psi for the hose-drum unit drive; it drew fluid from an oil reservoir mounted on the power unit, which was pressurized to between 45 and 55 psi, by the means of a pressure-reducing valve and an air bottle charged to a pressure of 2,000 psi nominal.

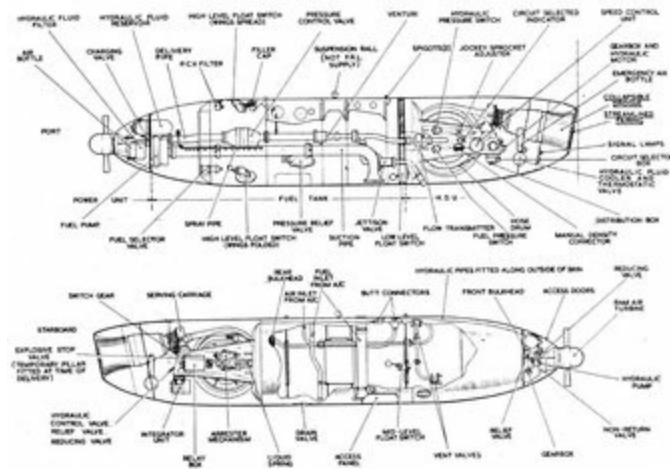
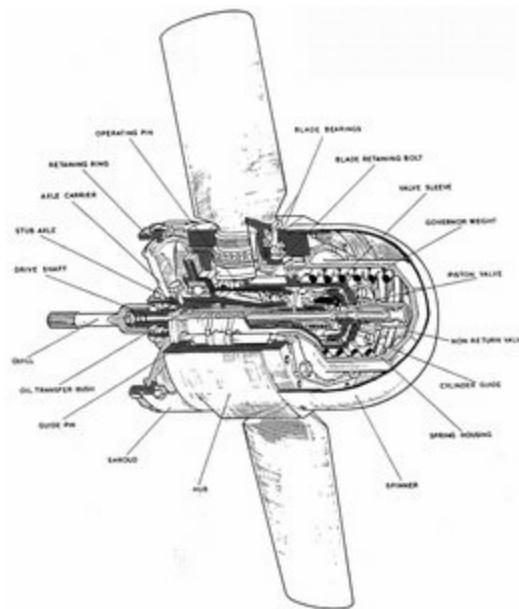


Fig. 187. Mk 20A refuelling pod, showing disposition of components

The ram air turbine ([Fig 189](#)) was a constant-speed device, which incorporated variable-pitch blades controlled by a centrifugal governor mechanism that actuated a hydraulic servo valve directing hydraulic oil pressure to a sliding cylinder to which the blade operating pins were connected. When not in use the blades were driven to the nearly feathered condition, thus providing the minimum drive to keep the system warm.

Fig. 189. Dowty 10/1 ram air turbine



The turbine was supplied with hydraulic fluid from the pod's hydraulic system for its operation, which was directed via a pressure-reducing valve to a selector valve. This valve permitted a selection to be made of either 'normal governing' or 'flight feathering', as shown in [Fig 190](#). In the former position, hydraulic fluid at 500 psi (34 bar) was fed to a piston-valve operating a sleeve within the turbine drive shaft, the position of the valve being controlled by centrifugal weights. The piston valve either (a) controlled the supply of fluid to the front of the piston causing the cylinder to move forwards towards fine pitch against a heavy spring, resulting in a rise in speed and torque, or (b) shut off the pressure supply and opened the cylinder to drain, the return-spring pressure, together with the torsional moment of the blades, causing a coarser pitch selection to be made, which resulted in a decrease in speed and torque. The governor weights were loaded by the combined pressure of the main governor spring and auxiliary spring. In order to accurately calibrate the piston-valve operation, the load of the auxiliary spring could be accurately adjusted by means

of shims.

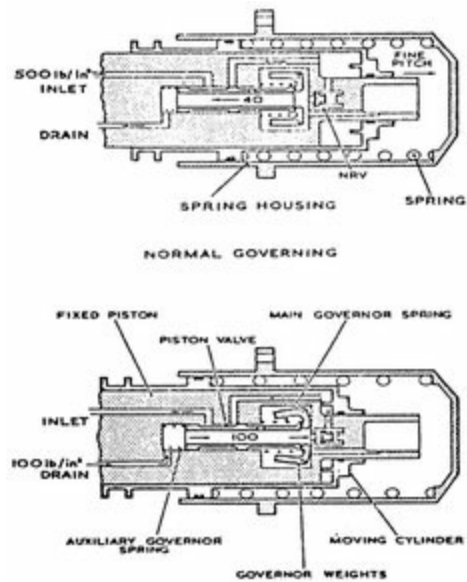


Fig. 190. Ram air turbine functional diagram

With the control valve in the 'flight feathered' position, the normal pressure supply and drain line connections were reversed so that hydraulic fluid was supplied via a stop-valve (further reducing the pressure to 100 psi (6.8 bar) along the drain line to the rear of the piston. The fluid passed through the non-return valve to the front of the piston and returned to the refuelling pod's hydraulic reservoir via the piston-valve, which, owing to the decreased-speed centrifugal force, it would fully open. This circulation of fluid through the turbine when in the feathered position served to maintain a working temperature at altitude. In order that hydraulic pressure was available for this requirement it was necessary for the unit to rotate at between 500 and 1,000 rpm in the flight-feathered condition.

The power unit gearbox ([Fig 191](#)) comprised a body into which were fitted a main drive shaft that mated with the quill shaft of the ram air turbine, a gear train, a gear assembly that drove the hydraulic pump, an oil-pump

assembly that provided lubrication through an oil-spray system, and a relief valve and filter, also for the lubrication system. The front face of the body formed the attachment surface for the ram air turbine.

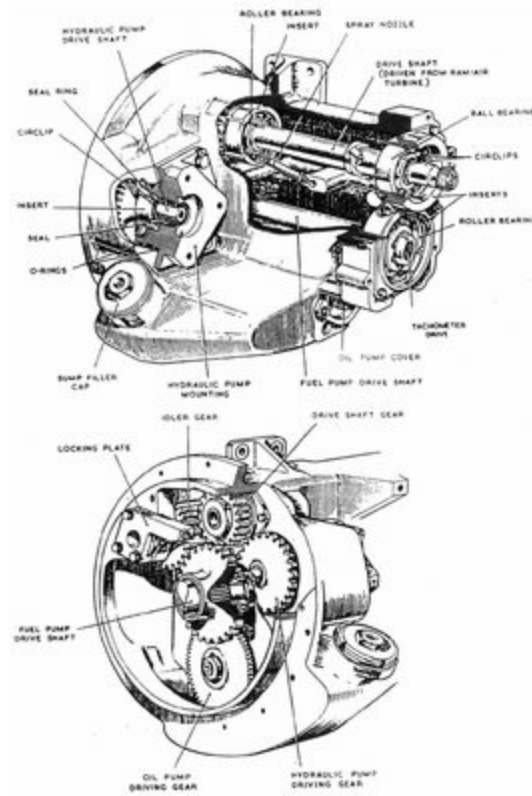


Fig. 191. Mk 20 power unit gearbox

The body of the gearbox was cast in aluminium, on the starboard side of which was a filling point for the oil sump, the latter forming the lower half of the casting. The rear wall of the casting was flanged, and had a spigot for the power unit to be secured to the fuel-tank via what was termed a 'cover plate', which was a thick metal disc.

The main drive into the gearbox was initially provided by the quill shaft connecting to the main drive shaft, and at the rear end of the main drive shaft a 19-toothed gear was fitted, this meshing with an idler gear. The drive from the quill

An internally drilled locking plate, secured to the body, served a dual purpose of locking the idler shaft against rotation and spray-lubricating the adjacent mating gears.

that formed an essential part of the gear train. The rear end of the shaft was fitted with two gears in tandem. The rear one, of larger diameter, meshed with the idler gear to transmit the drive from the quill shaft to the fuel-pump shaft. The front gear on the shaft meshed with a gear on the oil-pump shaft to drive the hydraulic oil pump.



The major component of the hydraulic pump drive assembly was a mounting block fitted through the wall of the gearbox body, which incorporated the pump's drive shaft and driving gear. The 26-toothed gear was driven by the engagement with the rear gear of the two gears on the fuel-pump shaft. This assembly is shown in [Fig 193](#).

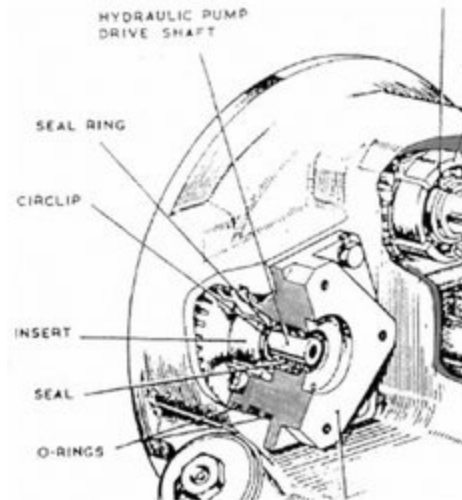


Fig. 193. Mk 20 refuelling pod hydraulic pump mounting

Similarly, the geared oil-pump assembly for lubricating the gearbox consisted basically of a geared shaft that was driven via a 65-toothed gear engaging with the front gear of the two gears on the pump shaft driving two gears within the pump's body.

A gearbox oil relief valve was fitted to the gearbox body, which was located immediately above the hydraulic oil-pump mounting, and was set to release oil back into the gearbox sump if the pressure within the gearbox exceeded 30 psi.

Provision was made for the gearbox oil to drain via the fuel-pump casing to a sump tank mounted within the fuel-tank; to prevent leakage through the gearbox breather under aircraft wing-fold conditions; oil returned to the gearbox when the wing spread condition was assumed.

The spray lubrication of all bearings and gears other than those contained in the oil-sump assembly was affected by the oil being pumped through various channels in the gearbox by the oil pump. This was self lubricating as it was almost completely submerged in oil when the sump was full. The pump delivered the oil in excess of 6 psi, at an oil temperature of 20°C, and this was not allowed to rise above

75°C when the power unit was running at peak revolutions.

A tachometer, fitted to the front end of the fuel-pump drive shaft and connected electrically to a detector unit in the pod's relay box, detected any overspeed condition of the ram air turbine. It was mounted in the lower bore of the turbine mounting.

The fuel pump, as shown in [Fig 192](#), was originally designed by Pulsometer Pumps of Reading, and given the designation of PFR 9000, of which the Mk 4 is illustrated. SPE of Slough bought the rights of the Pulsometer aircraft pumps and produced the first of the type. It was a two-stage centrifugal pump designed specifically for the Mk 20 series of refuelling pods. It was eventually taken over by the Plessey Company at Titchfield, Hampshire, which continued to produce it and provided an overhaul programme.

In the operation of the fuel pump, the pressure was built up in the pump as the radial velocity of the fuel, which was under pressure from the pod's air pressurization at the pump's inlet, was increased by the centrifugal head impressed upon it by the rotating vanes of the first impeller, the fuel passing through the increasing area of the diffuser passages converting the velocity into a pressure head. The fuel then passed to the inlet of the second-stage impeller via the passages in the middle chamber. The second stage would increase the pressure head again by the same amount as the first stage, to give a fuel transfer rate of 150 imperial gallons (675 litres) per minute at 50 psi at the pod's reception coupling.

The fuel tank formed the primary structure of the Mk 20 series of refuelling pods ([Fig 194](#)). The structure at the forward end permitted the attachment of the power unit, while the aft end supported the complete hose-drum unit with reception coupling and drogue. The tank was of light-alloy riveted construction, and was built up of six circular frames, which were secured to stringers at varying distances

apart, the outer skin being attached to these members to provide the necessary structural rigidity.

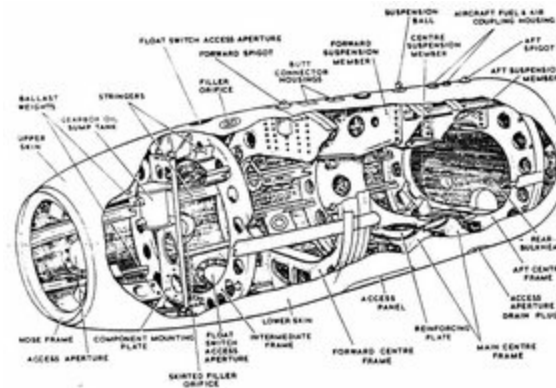


Fig. 194. Mk 20 refuelling pod fuel tank structure

The cover assembly of the power unit with the hydraulic reservoir and fuel pump was bolted to the nose frame of the structure, and a bulkhead was attached to the aft end, the latter consisting of a honeycomb and U-channel ring, completing the structure. The tank with the power unit fitted formed a complete compartment, which was pressurized, the structure being sealed with a sealant between all faying faces.

The tank comprised the forward and centre sections. The forward was a simple structure with the cross-sectional dimension diminishing towards the nose frame. The second frame was larger and ring shaped, with a flange. The web of it was deeper, with lightening holes, together with brackets attached at the top and bottom on the front web to accept a mounting plate for the fuel system components. The forward section was butt-strapped to the centre section, which was riveted equally to the inside of the skin panels of both sections. Stringers projected aft from this joint, which were riveted to the centre-section skin. There were circular access panels to which 'Wing-fold' and 'Wing-spread' high-level float-switches were fitted. A filler orifice was also fitted in

the skin to the port upper access aperture, and a skirted filler located on the starboard side was adjacent to the lower access aperture. The latter and lower float-switches were provided so that the refuelling pod was adaptable to aircraft with fixed or folded wings.

The centre section was of a similar construction to that previously described; however, this was built with four heavy double frames with plates reinforcing their interior flanges. The entire weight of the pod was concentrated on three suspension members located at the top of the centre section between the frames, and the whole of this assembly was bolted together, thus distributing the loads applied to the pod.

The three suspension members were light-alloy castings, each of a different shape and length, but the transverse section of each member was U-shaped and uniform in width, and the ends of these were all webbed and extended beyond each side for a short distance. The top of the forward member had three sunk housings located on the centre line to accommodate the aircraft pylon spigot and two electrical butt-connectors. The centre member housed a suspension ball, and the third aft member housed two small-bore housings for the fuel and air pylon inlet connections, together with the aft pylon spigot.

To afford the structural strength required for a large flat surface in a pressurized tank, the rear bulkhead was constructed in the form of an aluminium-foil honeycomb assembly. This was 1.75 inches (44.5 mm) thick, made up of eight segments, each segment being ranged at right angles to the centre radii of the segments, and each segment being separated by a plate. The cells and segments were all bonded to each other, and the assembled honeycomb was skinned with alloy sheets. Circular apertures were machined in six of the segments to receive mounting blocks for the various fuel pipes and electrical connections

The rear face of the honeycomb assembly was bolted to the front flange of a U-shaped channel ring frame. The frame to which the fuel-tanks' skin panels were riveted also carried the hose-drum unit and rear fairing.

The main access aperture was located in the lower centre section of the fuel-tank structure, and small access panels were provided for the various services and components, and all of the apertures to the panels were reinforced with a frame incorporating a step to which the panels were secured.

Four ballast weights were attached to the inner surface of the fuel-tank skin between alternate stringers immediately aft of the nose frame. They were rectangular in shape and curved to fit the forward section. The weights weighed a total of 100 lb and were incorporated in the pod's structure to alleviate flutter at low airspeeds.

In order to drain off the gearbox oil under the wing-fold condition, as previously mentioned, a small cylindrical tank capable of withstanding the high pod pressurization was fitted in the forward section of the fuel-tank above the level of the fuel pump. Two cone adaptors were screwed into sockets welded to the cylinder from which two oil pipes were connected to a block at the forward end of the fuel pump.

The fuel transfer system shown diagrammatically in [Fig 195](#) comprised the PFR 9000 fuel pump, fuel spray rakes, a combined fuel shut-off and pressure-control valve, a fuel-selector valve and a fuel-jettison pipe incorporating a jettison valve.

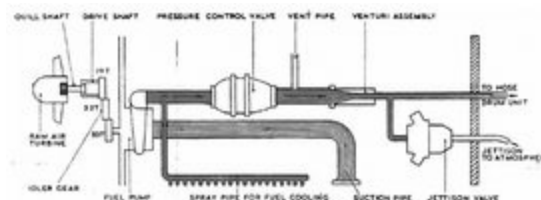


Fig. 195. Mk 20 refuelling pod fuel transfer system

The fuel pump was a two-stage centrifugal pump driven via the engagement of its drive shaft with the idler gear of the gearbox. The fuel was drawn into the pump through a suction pipe, which extended aft and almost to the bottom of the fuel tank. Fuel under pressure from the pump passed through a delivery pipe in which the combined fuel shut-off and pressure-control valve was fitted. When the shut-off portion of the valve was in the 'Closed' position, and the fuel pump was running in the stalled condition, to prevent the fuel from overheating two small-bore pipes, each fitted with thirteen nozzles, and termed spray rakes, were incorporated between the fuel pump's outlet and inlet to the control valve. These pipes were routed close to the fuel-tank's skin so that the fuel taken from the pump's outlet sprayed directly onto the skin, so that any heat generated was dissipated by the contact with the cold skin.

Control of the fuel pressure delivered from the pump to the reception coupling was by means of the combined fuel shut-off and pressure-control valve inserted in the main delivery pipe from the fuel pump. The shut-off function was controlled electrically via a separate solenoid-operated fuel-selector valve, while fuel-pressure control was effected mechanically in conjunction with the venturi fitted in the delivery pipe downstream of the control valve. The control system is shown in [Fig 196](#).

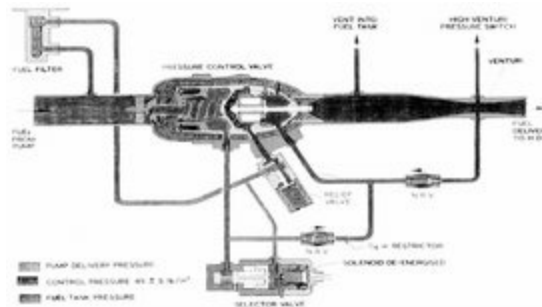


Fig. 196. Mk 20 refuelling pod pressure-control system

The control valve body (Fig 197) comprised three interconnected shell castings incorporating the internal shut-off valve at the inlet end, and a servo mechanism at the outlet end; a relief valve was connected to the control valve externally in conjunction with the servo mechanism.

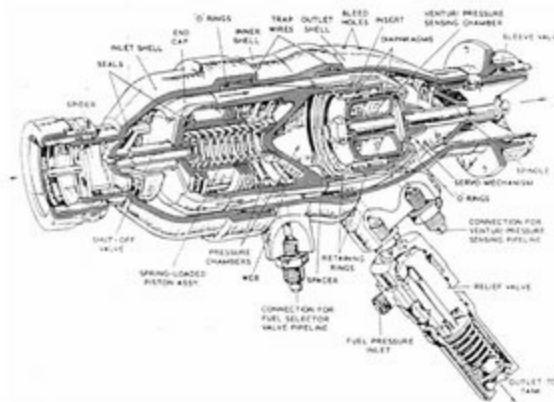


Fig. 197. Mk 20 refuelling pod pressure-control valve

The shut-off valve (Fig 198) assembly comprised a mushroom-head valve with a spring-loaded piston attached to its stem; the valve, when closed by the spring, plus the fuel-pump pressure locked below the piston, seated against a shoulder formed by the beaded connection of the inlet shell; simultaneously the piston sat against a shoulder inside the end cap, which fitted over the internal cylinder of the inner shell. The piston interior, with its scraper rings, formed a pressure chamber within the cylinder; fuel under pressure entered the chamber via three bleed-holes in the valve head and its hollow stem.

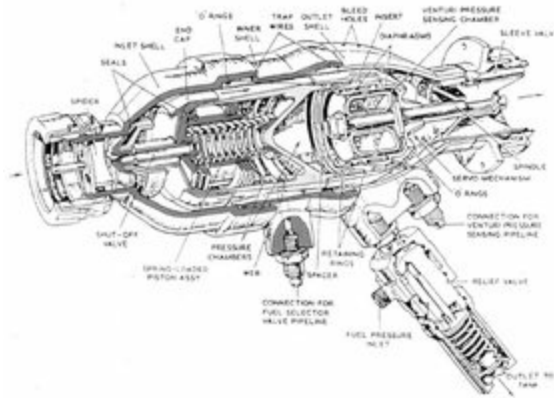


Fig. 198. Mk 20 refuelling pod shut-off valve control valve

The servo mechanism (Fig 199) comprised a diaphragm assembly, mounted inside the outlet shell pressure chamber, which was connected by a spindle to a sleeve valve, sliding in the neck of the fuel-flow passage; the diaphragm separated this chamber into two parts, which under working conditions contained fuel at a pressure governed by the relief valve on the upstream side, and fuel at the venturi pressure on the downstream side. Air was released from the venturi chamber, through a bleed-hole in the outlet shell web, to the fuel-tank. Variable linear movement of the diaphragm dictated by the venturi would cause the sleeve valve to regulate the fuel flow through the control valve by limiting the annular fuel passage around the pressure chamber.

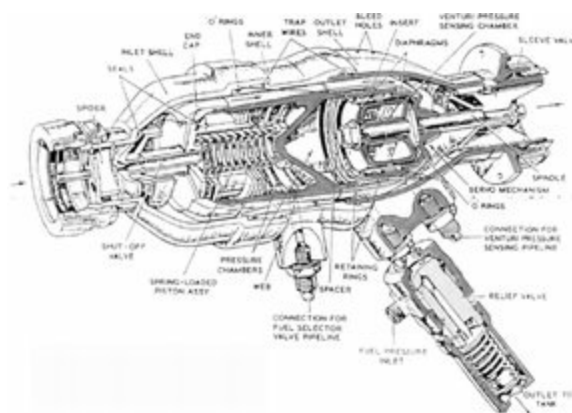


Fig. 199. Mk 20 refuelling pod servo mechanism control valve

The relief valve body housed a valve block and a spindle valve. This valve was loaded by a spring housed in an outlet casing, which was attached to the bottom of the valve block. The valve was unseated by excessive fuel pressure from the upstream side of the control-valve diaphragm, bypassed through the valve block into an annular space above the valve, the outlet casing, and thence into the fuel tank. The side of the body was provided with a fuel-pressure inlet, which connected with an annular groove surrounding the valve block; bleed-holes from this groove connected with the fuel bypass and a central area above the valve spindle in the valve block. Fuel-pump pressure was transmitted to act simultaneously on the spindle valve to the upstream side of the control-valve diaphragm, thus opening the valve when the fuel pressure exceed 43 psi.

The fuel selector valve ([Fig 200](#)) was pressurized through a pipeline and filter from the fuel delivery, and was connected to the pressure-control valve via another pipeline; it was actuated by a solenoid, which, when energized, opened the shut-off valve for the passage of fuel, and when de-energized closed the valve.

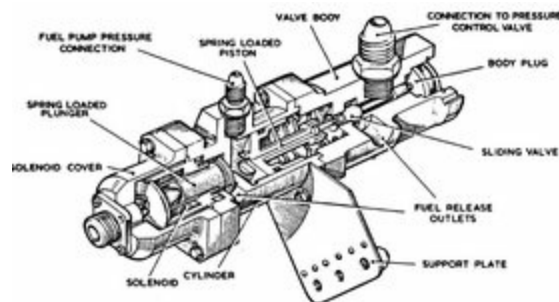
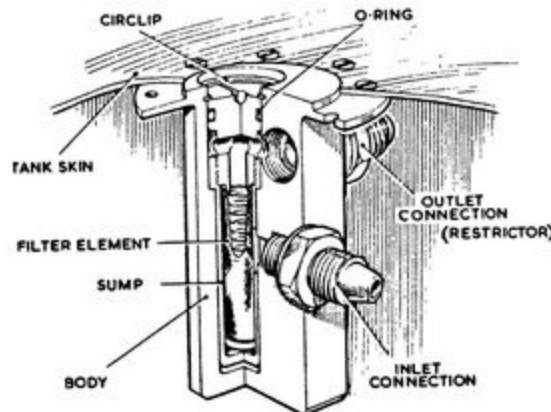


Fig. 200. Mk 20 refuelling pod fuel selector valve

In the de-energized state the solenoid plunger seated over

the outlet of a piston cylinder, and fuel-pump pressure acted upon the selector piston to close a second outlet with its sliding valve. In this condition, fuel was trapped below a spring-loaded piston of the shut-off valve to keep the latter closed. When the solenoid was energized, the plunger was withdrawn and the pump pressure released, and the spring-loaded selector piston and its valve would extend to open the second outlet through which the fuel trapped below the shut-off valve piston was released.

The filter ([Fig 201](#)) in the pressure-control system ensured a clean flow of fuel, primarily to the relief valve, and secondly to the selector-valve pressure chamber. The filter for this purpose, located at the top of the fuel-tank and attached to a skin panel internally, comprised a body incorporating a filter element. A lower inlet union passed fuel through the element, to emerge at the top of the element and thence through an outlet restrictor.



[Fig. 201](#). Mk 20 refuelling pod pressure control filter

The venturi sensed the fuel pressure at the reception coupling ([Fig 202](#)). At the throat of the venturi were two tappings, one at the top, which connected with a pressure-switch, and the second at the bottom, which connected to the servo.

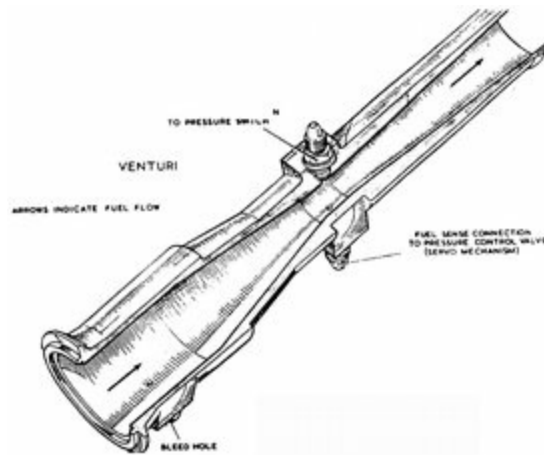


Fig. 202. Mk 20 pod Venturi

In the overall fuel shut-off and pressure-control system in the no-flow condition, the ram air turbine on the power unit was in the feathered condition, and so there was a very low flow being supplied, which was exhausted into the fuel-tank via the two spray rakes, thereby applying virtually no fuel pressure to the front of the shut-off valve, the fuel-selector valve being in the de-energized state, thus keeping the valve closed. The servo mechanism operated in conjunction with the venturi, the latter solely detecting the fuel pressure at the reception coupling, thereby conducting the detected fuel pressure to the pressure chamber of the mechanism's diaphragm. In the no-flow condition the mechanism's sleeve valve would be open, owing to the following factors. As there was no fuel pressure at the venturi throat there would also be no fuel pressure applied to the pressure chamber downstream of the mechanism's diaphragm. As the fuel pump was running at a low speed (the ram air turbine being in the feathered condition), a low fuel pressure would, however, be applied to the pressure chamber upstream of the mechanism's diaphragm, though insufficient to be relieved through the pressure-relief valve, so that the sleeve valve would be open.

In the fuel-flowing condition, initially the ram air turbine

was selected to the unfeathered condition, thus providing power to the fuel pump, the fuel-selector valve being energized. The fuel was now supplied under pressure to the front face of the fuel shut-off valve, and via the filter through the piping to the fuel-selector valve and pressure-relief valve on the control-valve body. The selector valve with the solenoid in the energized condition allowed trapped fuel within the shut-off-valve pressure chamber to be exhausted into the fuel tank, and so with the fuel pressure applied to the face of the shut-off valve it automatically opened, permitting fuel to flow through the control-valve body, through the venturi and thence to the reception coupling.

When the fuel was flowing, the relationship between the servo mechanism and venturi was such that the latter detected a fuel pressure of 50 psi (3.4 bar), the flow through the control valve and back through the sensing line was in balance, and thus the servo-mechanism sleeve valve was open sufficiently to permit a constant flow through the control valve. A fuel pressure upstream of the servo-mechanism diaphragm of approximately 45 psi (3.0 bar), depending on the fuel-pump pressure, was governed by the relief valve, which sat over an outlet upstream of the servo-mechanism diaphragm and would relieve any excessive pressure back into the fuel-tank. The two non-return valves in the pressure-control system, one of which was fitted in the venturi-throat sensing line to the servo-mechanism pressure chamber downstream of the diaphragm, permitted the venturi throat pressure to enter the chamber. The other, located in a sensing line tapped into the venturi throat line and connected to the fuel shut-off pressure chamber, prevented the venturi throat pressure entering it, though it allowed a locked static pressure when no fuel was flowing to enter the servo-mechanism pressure chamber downstream of the diaphragm, thereby balancing the pressure within the control-valve assembly.

Assuming a condition such as when the receiver aircraft

closed its fuel-tank refuelling valve (tank full), the venturi throat would detect a rise in pressure denoted by a reduced fuel flow through it; an increased fuel pressure would therefore be present in the sensing line to the servo mechanism. The pressure acting upon the pressure chamber downstream of the diaphragm would be greater than that upstream, as the latter was limited to 45 psi (3.0 bar) via the relief valve. The servo-mechanism sleeve valve would thus move towards its closing position, and a reduced flow would be passed through the control valve. If, however, the fuel pressure was sustained at a high level of 72 psi (4.9 bar) for two seconds, the pressure-switch in the upper venturi sensing line would signal the fuel-selector valve solenoid to de-energize, thus closing the fuel shut-off valve. The fuel pump would then be running in the stalled condition, the fuel being exhausted into the fuel-tank via the spray rakes. If a high pressure was not sustained and was only a transient pressure rise, the two-second time delay incorporated in the electrical system to the fuel-selector valve solenoid, the fuel shut-off valve would remain open and the fuel transfer continued.

The above has described the fuel-transfer system only. However, other important features were incorporated within the fuel-tank to enable it to operate as a drop tank, as shown in [Fig 203](#), showing the Mk 20B system). As mentioned in the fuel-transfer system, a fuel-jettison line was teed into the fuel-transfer line downstream of the venturi. The purpose of this was to enable the tanker aircraft to dump fuel through the refuelling pod, together with its contents, in the event of an emergency, at 85 imperial gallons (382 litres) per minute, thus in a serious emergency losing a sufficient weight of fuel to achieve the aircraft's required landing weight. The teed jettison line was connected to a Mk 2, Series 3, Flight Refuelling Ltd jettison valve, the outlet of which joined a fuel-jettison pipe that passed through the fuel-tanks' rear bulkhead into the hose-drum unit bay and out to atmosphere at the bottom of the bay.

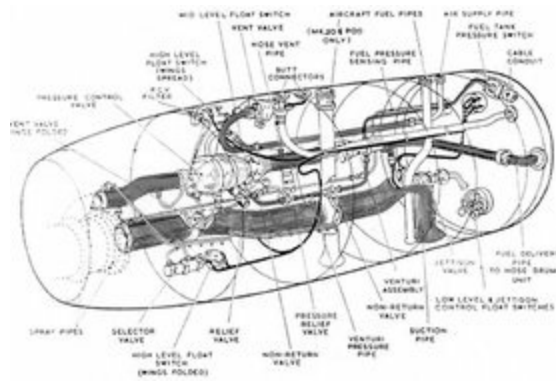


Fig. 203. Mk 20 pod series overall fuel system

The fuel jettison valve (Fig 204) had a high opening pressure to enable the fuel to be jettisoned speedily from the fuel tank.

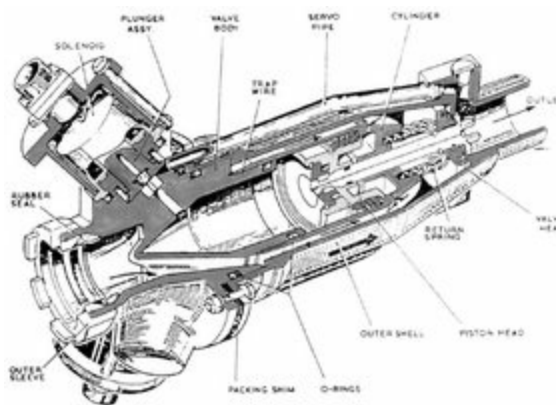


Fig. 204. Mk 20 pod series fuel jettison valve

The outer shell was flanged for attachment to a valve body, and had an outlet 1.25 inches (31.75 mm) in diameter, which provided a seat internally for a valve head. The fuel inlet to the body was fitted with an outer sleeve, split collar and rubber seal for connections to a fuel-delivery pipe. A conical housing, supported by a web integral with the body, formed a mounting for a cylinder housed within the outer shell. Externally two mountings were formed on the body diametrically opposite each other to house solenoid

assemblies, and two exhaust passages in the web connected the conical housing with the mountings. Two grooves in the valve body accommodated O-rings to seal the joints between the body and the outer shell and cylinder. The latter was secured to the body by a trapped wire retained in corresponding grooves. Two servo pipes were located between the solenoid mountings and bosses formed on the outer shell to enable fuel to pass from the cylinder chamber into the jettison pipe via the exhaust passages; these pipes were sealed with O-rings at their entry to the components.

The internal cylinder, which contained piston and valve-head assemblies, had breather holes spaced radially around the downstream end between a piston seal seating in the cylinder bore and valve guide in its tapered end. When the jettison valve was de-energized, the valve head was spring-loaded against its seating in the outer shell, and its stem passed through the guide into the cylinder. The piston assembly, comprising a piston head with a sealing ring, three scraper rings located by spacer rings in between, and secured by a circlip, was a sliding fit in the cylinder bore. The piston head was located on the valve stem by a split collar and its retaining collar, which in turn was secured by a circlip. Fuel pressure was maintained by an O-ring fitted in a groove around the stem.

A sealed solenoid unit and plunger valve was housed in each solenoid mounting, the plunger valves being spring-loaded to close against a bushed seating in the exhaust passages. When the solenoids were energized, the plunger valves were drawn inwards, thus opening the fuel passages. An electrical plug was mounted in each solenoid cover, and the assemblies were secured to the mountings.

In the operation of the valve when the solenoids were de-energized, the solenoid plunger valves, the piston seal and the valve head were all closed against their respective seatings; the inner and outer cylinder chambers were equally pressurized with fuel.

Under fuel-flow conditions, before the fuel could be jettisoned the solenoids had to be energized, which caused the solenoid plunger valves to be withdrawn from their seats; fuel pressure would be released from the inner cylinder chamber and fuel would pass via the exhaust passages and servo pipes to the valve outlet. More fuel from the valve inlet would immediately enter the outer-cylinder chamber through the breather holes, and this fuel pressure would lift the piston and valve head from their seats simultaneously, and allow fuel from the valve inlet to pass unrestricted through the annular space between the outer shell and the cylinder, to be jettisoned through the outlet.

When the circuits to the solenoids were broken by the action of a float-switch, the solenoid plunger valves were released and closed the exhaust passages. The piston and valve assembly would also close, due to the action of the return spring, after a settling period, during which time the inner and outer cylinder chambers would be pressurized with the remaining fuel.

Five Flight Refuelling Mk 4 float-switches were fitted inside the fuel-tank; three were of the single-float type, and the fourth was a double-float type. Two of the single type were for high-level operation, the third for mid-level. The high-level float-switches functioned in the same manner and for the same purpose, to ensure that when the fuel-tank was full a refuelling valve or valves in the parent aircraft's fuel system were closed. This was achieved by an electrical signal originated when the float-switch reached the fully-floating position, and transmitted to the solenoids of the refuelling valves. One switch was fitted forward of the tank's suspension member and operated when the refuelling pod was in the normal flying position; the second switch, located low down on the starboard side of the fuel-tank, operated only when the wings of the parent aircraft were in a folded position during a ground refuelling operation. A mid-level float-switch, attached through a lightening hole on the

starboard side of the forward centre frame, was provided to prevent the shut-off valve in the pressure-control valve from opening and transferring fuel from the fuel-tank following the operation of the low-level float-switch, until the fuel within the tank contained 80 imperial gallons (382 litres).

A double float-switch was fitted low down on the fuel tank's rear bulkhead, the floats of which were installed at the same level, and their mechanisms were connected separately to operate the fuel shut-off valve in the pressure-control valve and the fuel-jettison valve. One float was used for normal fuel control, to close the fuel shut-off valve when the fuel-tank had been emptied to such an extent that it permitted the float to drop to its lowest level, and at this position caused the de-energizing of the fuel-selector valve solenoid.

The second float-switch of the double unit was used for fuel control during the fuel-jettison procedure. The condition only occurred after the fuel-jettison switch on the refuelling pod's control panel had been set to 'ON', and closed the parent aircraft's refuelling valve or valves. As soon as sufficient fuel had been jettisoned to permit the jettison float to fall to its lowest level, a further electrical override caused the jettison valve and the fuel shut-off valve to close. By this means a minimum quantity of fuel was retained within the tank, and the entry of air into the fuel pipes was prevented.

A typical Mk 4 series float-switch is shown in [Fig 205](#). The unit comprised a circular base plate with a rectangular pillar projecting from one face, to provide a mounting for a switch plate and spindle, and two diametrically opposite lugs on the other face. A spigot formed on the base plate located it in the mounting assembly. Between the two small lugs the base plate was machined out, so that a thin wall 0.045 inches (1.10 mm) in thickness remained. This wall acted as a gap between a permanent magnet on the switch side of the plate and an armature on the float side.

An actuating arm was mounted on the pivots about the spindle fitted in the pillar, and the permanent magnet was attached horizontally to the lower end of the arm so that its pole pieces could butt against one face of the 0.045-inch wall. Mounted at the upper end of the arm was a brass balance weight, which served as a mass balance to minimize the effect of acceleration and gravity. The adjustable grub screw that secured the balance weight to the arm extended beyond the weight and acted as a limit stop for the arm. Adjustment of the screw increased or decreased the movement of the magnet. Positioned on the arm between the spindle and the balance weight was an adjustable striker, which bore against the operating button of a microswitchette rigidly mounted to the switch plate.

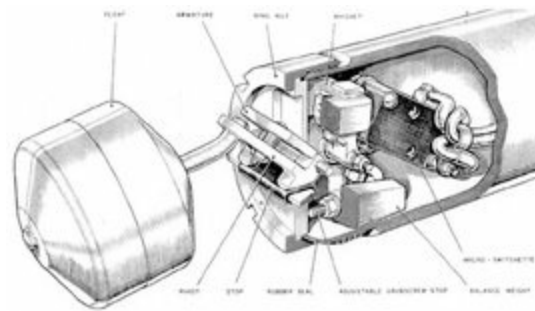


Fig. 205. Mk 4 series float-switch

The float assembly consisted of a pivot, an armature, a float arm and a metal float. The triangular brass pivot had two right-angled lugs formed at its base, which received the pivot pin. The cadmium-plated steel armature was rectangular in shape. When the armature and pivot were assembled together, a stud that was screwed into the armature protruded through the opposite face of the pivot. A slot cut in the end of the stud permitted it to be rotated, so that the gap between pivot and armature, and between armature and diaphragm, could be increased or decreased. The float arm was attached at one end to the apex of the

pivot, the other end being secured to the float. A light-alloy strip fitted with a protective rubber cover was secured across the base plate, providing a stop for the float arm.

In the functioning of the float-switch in the static condition, the position of the actuating arm was such that the end of the balance-weight adjusting screw bore against the base plate, and there was a gap between the 0.045-inch (1.10 mm) diaphragm. The actuating arm was maintained in this position by the recovery force of the microswitchette being applied to the adjustable striker. As the float was raised by an increase in fuel level, the armature was moved towards the magnet until a point was reached at which the magnet was attracted towards the armature and the magnet poles butted against the 0.045-inch diaphragm. When this occurred the actuating arm pressed the adjustable striker against the switchette button, thus affecting a change-over. Similarly, as the float fell and the armature was drawn further from the influence of the magnet, the recovery force of the switchette button pushed the magnet away from the diaphragm, and change-over was again effected.

To prevent over-pressurization of the fuel tank; a pressure relief valve ([Fig 206](#)), set to relieve at 23–25 psi (1.6 bar average), was fitted centrally of the fuel-tank via an outlet pipe on the lower starboard side of the tank skin.

Fuel entering the inlet body of the valve at a pressure between the 23 and 25 psi overcame a spring loading imparting a linear movement to the valve assembly. With the valve open, fuel or air could flow through the valve overboard from the tank. Relief-valve pressure was determined by the insertion of a shim between the valve head and spring support.

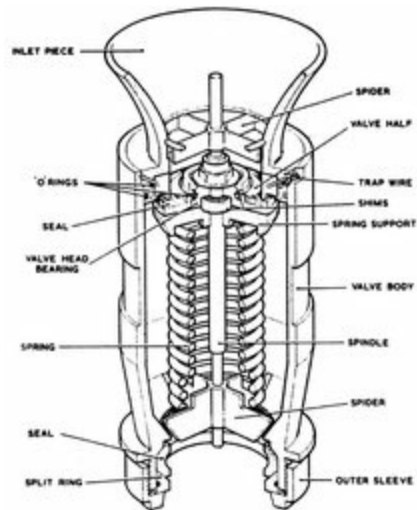


Fig. 206. Mk 20 refuelling pod tank relief valve

The fuel and air inlets from the parent aircraft were mounted in the rear suspension member of the tank structure, as shown in [Fig 207](#). Those illustrated were on the Mk 20A and 2C refuelling pods, however, and an additional fuel inlet of 3.00 inches (76.2 mm) diameter was added forward of the suspension point for the Mk 20B for the Victor tanker, and the Mk 20E, which made the latter of the series totally interchangeable between aircraft.

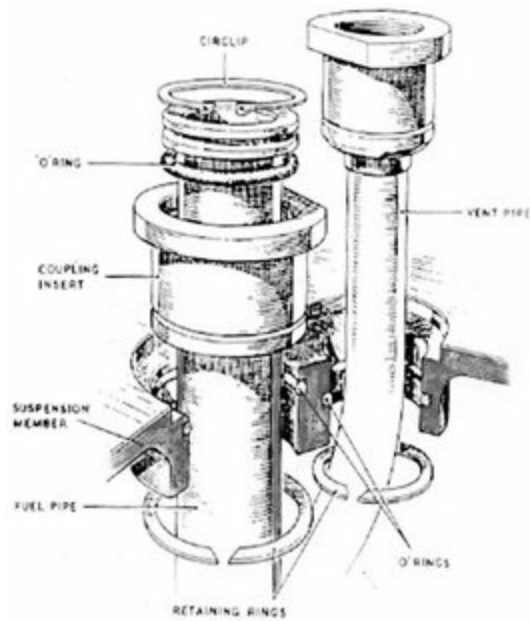


Fig. 207. Mk 20 pod fuel and air interface

Two twenty-four pole, spring-loaded, electrical butt connectors were mounted in separate machined recesses on the pod's centre line of the forward suspension member of the fuel-tank structure. The forward connector was mounted in a circular recess, the aft being in a rectangular recess. On the Mk 20B and 20E variants these were also located forward of the 3.00-inch fuel inlet.

Two vent valves were incorporated to vent the fuel-tank, which are shown typically in [Fig 208](#). These were similar in design, and comprised basically a float-operated pad valve, which when closed seated on a sealing face on the valve's body.

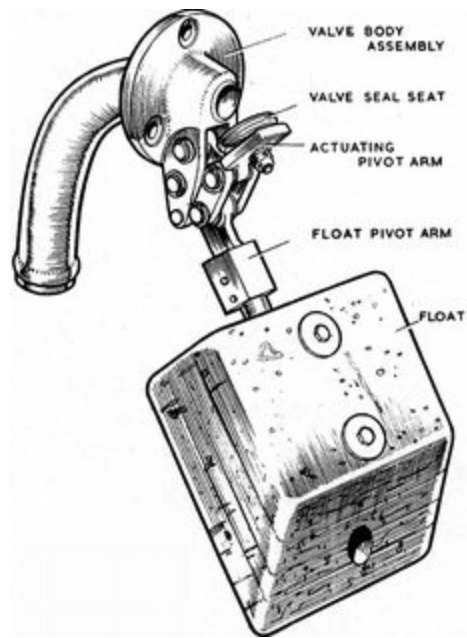


Fig. 208. Mk 20 pod float vent valve

The operation of the valve was that the linkage was so arranged that when an upward movement of the float was made, it was transmitted to the valve seat and the leverage was such that the rubber seal was pressed hard against the valve body's sealing face by the buoyant action of the float.

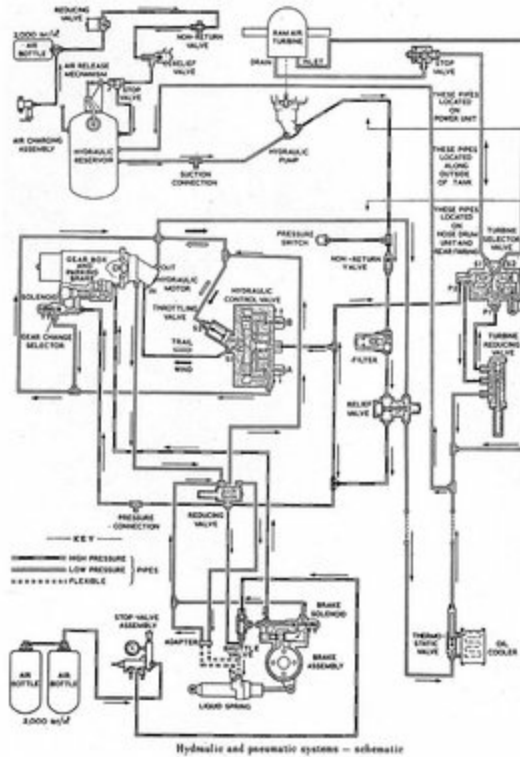


Fig. 209. Mk 20 refuelling pod hydraulic system

As the unit was hydraulically and pneumatically controlled in its operation, as well as having electrical signalling, it is necessary to describe these two systems before describing the hose-drum unit and its components.

The hydraulic system ([Fig 209](#)) supplied hydraulic fluid under pressure to a hydraulic pump from a reservoir adjacent to the power unit, and thence to the various components to operate the hose-drum unit and ram air turbine.

The hydraulic reservoir ([Fig 210](#)) was located adjacent to the power unit. It was oval in shape and flanged around its forward periphery for attachment to the cover plate of the power unit structure, the rear protruding into the fuel-tank through an aperture in the cover.

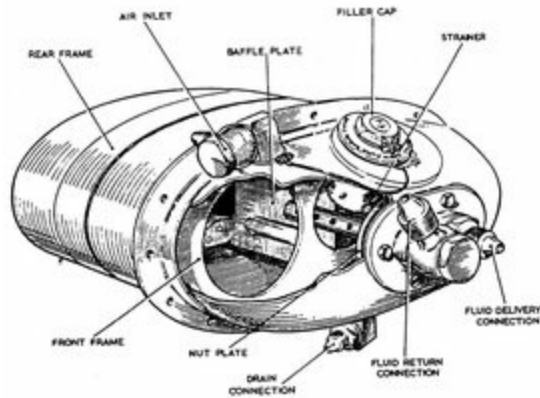


Fig. 210. Mk 20 pod hydraulic reservoir

The pneumatic system, the disposition of which is shown diagrammatically in Fig 211, provided a regulated supply of pressurized air to the hydraulic reservoir, thereby providing a pressure head to the hydraulic pump. The pressurized air was supplied to the system from a steel bottle charged to 2,000 psi (136 bar), mounted to the port side of the power-unit gearbox and retained by a hinged clamp. The bottle carried a double banjo adaptor, the inlet connection receiving a pipe from a charging valve assembly, and the outlet carried a pipe leading to a pressure-reducing valve, which reduced the air pressure entering the reservoir to 45–55 psi (3.4 bar average). The outlet pipe from the reducing valve led to a pressure-relief valve via a non-return valve, which relieved any excessive pressure within the reservoir. It was adjusted to vent to the atmosphere through its gauze cylinder wall when the air pressure rose above 60–80 psi (4.75 bar). The valve was mounted on the starboard side of the cover assembly.

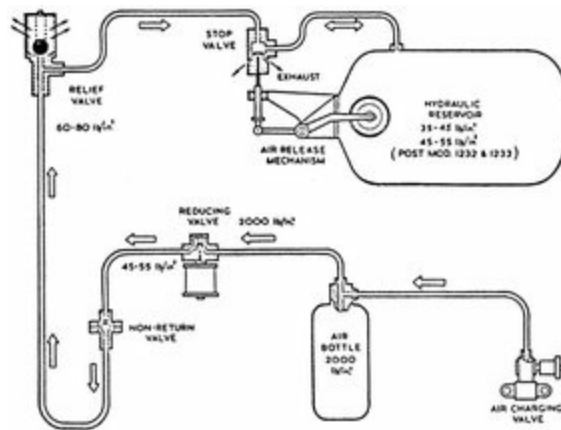


Fig. 211. Mk 20 pod pneumatic system

Incorporated on the front of the hydraulic reservoir was a combined stop valve and air release mechanism (Fig 212), which prevented the removal of the reservoir's filler cap. The stop valve in the operating 'OPEN' position was supplied with air from the outlet of the pressure-relief valve, and thence into the reservoir. It was operated manually via an operating rod connected to the lever on the air-release mechanism, which also acted as a guard for the filler cap. When the operating rod was pushed to its closed position, there was no airflow path to the reservoir, the air within the reservoir being exhausted to the atmosphere.

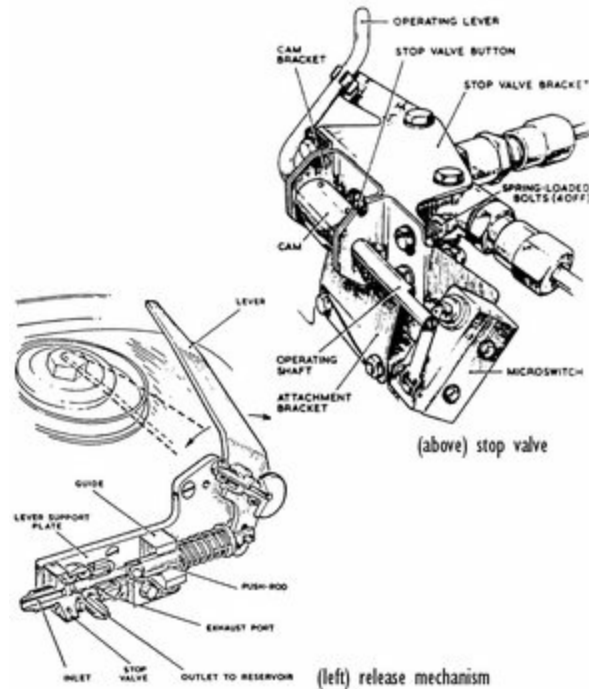


Fig. 212. Mk 20 pod air release mechanism and stop valve

The mechanism consisted of a lever pinned to a support plate with a bolt and plain bearing forming the pivot. A slot in the lower end of the lever received a pin, which passed the fork ends of a spring-loaded push rod. The push rod was connected at its other end to the operating rod of the stop valve, and was supported by a guide block bolted to the support plate. At its forward end, the stop valve was secured to the support plate by bolts that passed through its inlet housing and screwed into tappings in the lever support plate.

The lever had two positions, and to lock it positively in either of these positions, a spring-loaded plunger assembly was fitted to it. Two locating holes were provided in the support plate to engage the end of the plunger, and the assembly was secured to the front of the hydraulic reservoir.

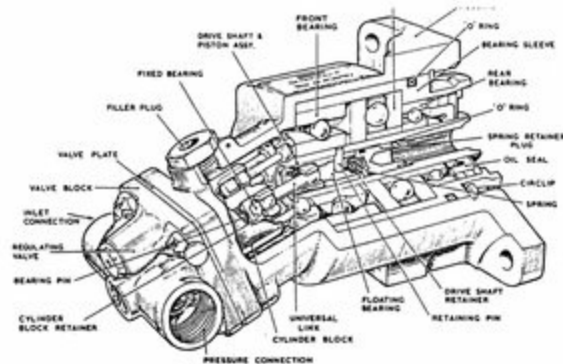
The operation of the stop valve and lever was such that when the lever was positioned over the reservoir's cap, the

push rod that was pinned to the bottom of the lever was pulled outwards, i.e. right viewed from the front of the refuelling pod. As the push rod was pinned at the other end to the operating-rod stop valve, the operating rod was pulled in the same direction. In this position the exhaust ports of the valve were sealed off and a flow path was opened between the inlet and outlet connection, allowing a continuous air supply of 45–55 psi to flow into the reservoir.

When the lever was moved outwards, away from the reservoir's filler cap, the push rod and the operating rod in the stop valve were pushed in the opposite direction. The inlet connection within the stop valve was then sealed off, cutting the air supply to the reservoir. Simultaneously, the exhaust ports in the valve were uncovered and a flow path was opened from the reservoir to the exhaust ports via the outlet connection of the valve. The air pressure within the reservoir was then exhausted through the ports, making it safe to remove the reservoir filler cap.

The pressurized hydraulic delivery line from the reservoir was connected to the inlet port of the hydraulic pump located on the power unit. The pump ([Fig 213](#)) was a Vickers constant-displacement pump, Type PF 77-3906-30, that delivered a continuous non-pulsating flow of hydraulic fluid to the refuelling pod system at 1.94 imperial gallons (8.73 litres) per minute at 3,500 psi (238 bar). Later, however, the power unit was modified to incorporate an improved low-temperature hydraulic pump, a Vickers PF 77-006-R006-82. This was necessary after using the original prototype Mk 20B pods on the early two-point Victor KP2 tanker aircraft.

[Fig. 213](#). Mk 20 pod hydraulic pump



The hydraulic pressure-supply outlet from the hydraulic pump ran externally along the top of the fuel-tank structure to its aft end, and on the starboard side within a small curved fairing. The line was the main supply for all of the hydraulically operated components on the hose-drum unit, and the ram air turbine blade pitch control. Prior to being teed into the various components, it initially incorporated a pressure-switch followed by an in-line non-return valve, high-pressure filter and pressure-relief valve.

The high-pressure filter ([Fig 214](#)) was of the microfilter type that incorporated a bowl containing a corrugated stainless-steel wire-gauze element surrounding a perforated core, thereby preventing foreign matter from circulating within the hydraulic system of the refuelling pod. In the event of the filter medium becoming clogged, the pressure differential between inlet and outlet pressures increased, causing a red button to appear from an indicator housed within the filter's body, to ensure that a full flow of hydraulic fluid was maintained if clogging was allowed to continue.

With normal flow through the filter, fluid from the hydraulic pump was passed to the annular chamber surrounding the spring-loaded element; after the fluid percolated through the element into the centre core it passed through holes in the hollow body spigot to the outlet. A spring-loaded diaphragm that slid down the spigot closing the inlet passage to and from the filter chamber enabled the element to be changed

without hydraulic fluid loss as the bowl was unscrewed for servicing. The filter was mounted on the bottom flange of the hose-drum unit's starboard side frame, adjacent to the hydraulic pressure-relief valve.

The pressure-relief valve ([Fig 215](#)) comprised a body that incorporated two opposing pressure and two return ports, together with a central bore to house the functional components. Four mounting bosses formed on the body with holes through them to secure the valve to a tie bracket on the hose-drum unit.

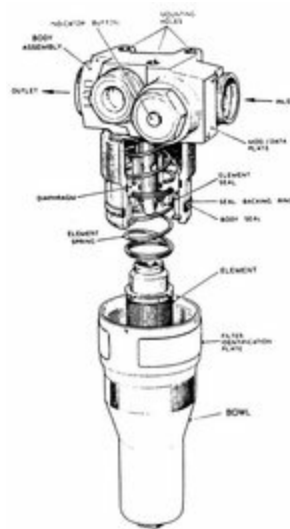


Fig. 214. Mk 20 pod high-pressure filter

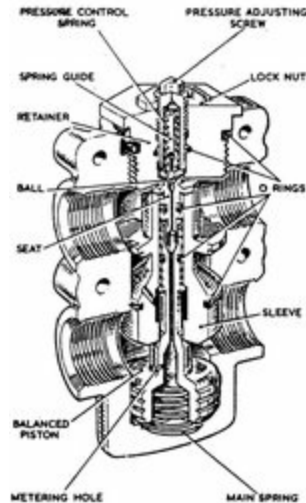


Fig. 215. Mk 20 pod pressure-relief valve

The piston and sleeve of the valve were mated parts. The large hollow end of the piston; which fitted precisely in the lower bore of the body, retained a main spring and formed a metering chamber. A metering hole in the piston stem allowed the hydraulic fluid pressure to enter the chamber, and when excessive, the hydraulic pressure could be relieved through a central hole in the piston and the ball-valve seat to lift the ball valve off its seat. The chamfered shoulder at the lower end of the piston was normally loaded by the main spring and the hydraulic pressure against a seat formed to seal off diagonal drillings in the lower end of the sleeve. High hydraulic pressure that built up in the pressure ports caused the piston to move on down due to the reduction in pressure in the metering chamber, and it was relieved through these drillings and slots in the upper port of the sleeve to the return ports.

A retainer, sealed with an O-ring, secured to the piston and sleeve in the housing; a pressure adjusting screw, also sealed with an O-ring and locked with a nut, turned into the centre bore of the retainer housing and adjusted the pressure-control spring. A guide within the spring was loaded onto the ball valve and seat above the piston.

The operation of the relief valve was fully automatic, and on a rising pressure it maintained closed until the preset relieving pressure was reached. At this point the valve opened and bypassed sufficient fluid to maintain the set pressure in the circuit, and as pressure fell the ball valve reseated. At pressures below the relieving pressure the piston was held on its seat by the main spring in balanced pressure conditions, because the feed of fluid at line pressure to the interior bore through the metering hole in the lower part of the piston. As soon as relieving pressure was

reached the ball valve lifted and vented the interior of the piston to the return line. Thus the piston was no longer in a condition of balanced pressure and was forced downwards against the main spring and away from its seat. As the pressure fell below the relieving pressure, the ball valve reseated and re-established the pressure balance in the piston, which was forced to its seat by the main spring.

The low-pressure outlet, or return line from the relief valve, was connected to the inlet of an oil cooler and thermostat assembly ([Fig 216](#)). The tubular oil cooler, Type No. C6416, was constructed throughout in light alloy, the thermostat being mounted on the inlet and outlet of the cooler.

When the hydraulic fluid in the system was cold, the thrustat plunger within the thermostat assembly was retracted, allowing the inlet valve in the assembly to open under fluid pressure, the fluid flowing through the thermostat to the hydraulic reservoir on the power unit and bypass the cooler. When the fluid was warmed up, the thrustat plunger would start to extend at 50 °C, due to the volumetric expansion of the melting wax inside the thrustat's cylinder. Gradually some of the fluid would be directed through the oil cooler, until at 75 °C the thermostat valve would be closed by the extending plunger and all the fluid would pass through the cooler to emerge through the

cooler's outlet opposite the thrustat. As the fluid cooled the thrust plunger retracted again.

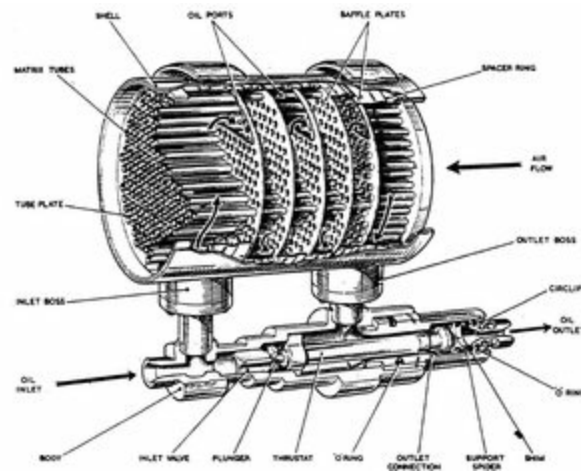


Fig. 216. Mk 20 pod oil cooler and thermostat

From the high-pressure outlet of the relief valve the hydraulic supply line teed off to the various hose-drum unit components, and so it is now necessary to include the hose-drum-unit assembly itself to achieve the correct context.

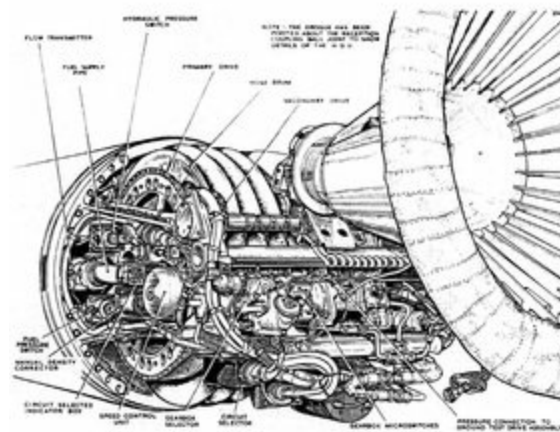
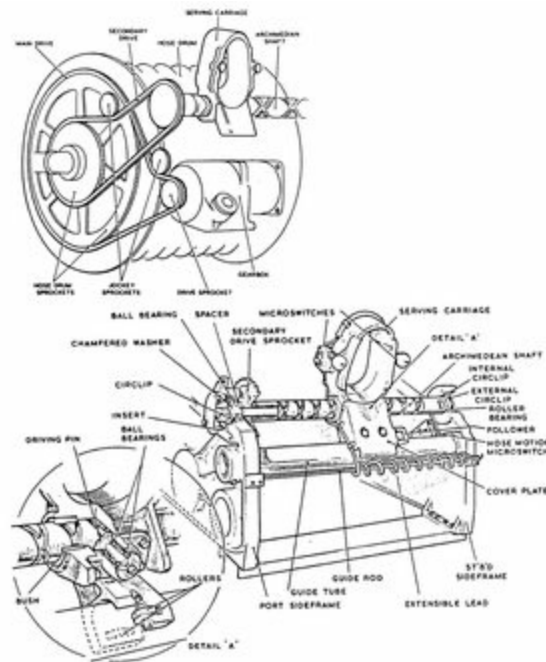


Fig. 217. Mk 20 hose-drum unit, port side

sprocket that regulated tension within the chain, the latter being taken from the hub of the drum to drive a refuelling-hose serving carriage (Fig 219) at the aft end of the unit.

Fig. 219. Mk 20 hose-drum serving carriage drive



The starboard side frame carried an electrohydraulic brake mechanism (Fig 220) and a liquid spring, the latter absorbing the shock loads when the brake was applied. Also mounted on the starboard side was the switch assembly, which incorporated three microswitches.

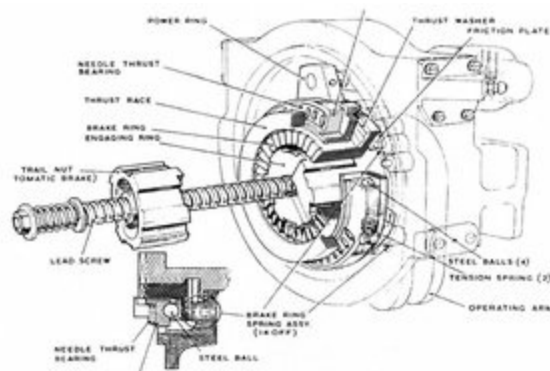


Fig. 220. Mk 20 hose-drum brake mechanism

The brake mechanism, together with its hydraulic and electrical operating mechanism, was housed in, or mounted on, the brake housing. The component parts were concentrically assembled in the centre of the housing, hydraulic pistons were accommodated within cylinder bores located above the centre housing, and the adapter of a pilot valve was inserted in an adjacent bore. A solenoid assembly was secured externally to the outer aft side of the housing. The brake housing, with the mechanism completely assembled, was secured to the hose-drum hub mounting on the outer side of the starboard side frame.

The components of the emergency and automatic brakes were independent. The principal components were an engaging ring, which carried the shaft of a lead-screw internally (a splined trail nut, to slide in the hose-drum splined hub, rotated the screw protruding from the inner face of the engaging ring); a brake ring, with its friction plate and thrust washer, which was splined externally on the engaging ring; a power ring placed over the brake ring; and a latch ring placed over the power ring.

The hydraulic mechanism ([Fig 221](#)) within the brake housing comprised two cylinder bores, one for a reset piston ($\frac{3}{4}$ inch diameter) and the other for a release piston ($\frac{5}{8}$ inch diameter) in a bore of the brake housing connected by drillings to a bore that accommodated a pilot valve adapter, these bores being located in the brake-housing casting above the brake mechanism. The hydraulic piston heads actuated the power-ring lever with a shuttle movement, the hydraulic pressure acting on the inside of both pistons differentially, due to the surface area, to provide this movement. The solenoid-operated pilot valve controlled the fluid pressure to the piston cylinders.

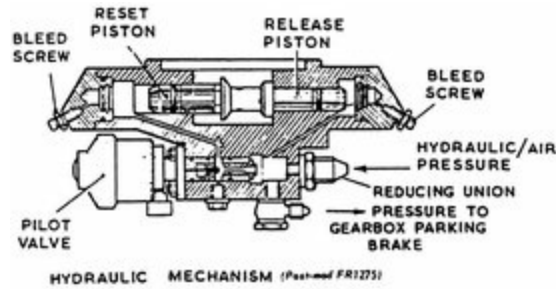


Fig. 221. Mk 20 hose-drum brake hydraulic mechanism

A brake-off solenoid was mounted on a plate that was secured to the outer face of the brake housing, as shown in Fig 222. The solenoid, when energized, attracted and held the armature plate, thus locking the brake in the disengaged position.

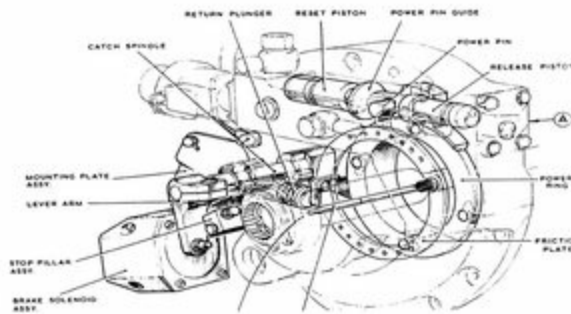


Fig. 222. Mk 20 hose-drum. Brake-Off solenoid position

A microswitch operated (Fig 223) by a spring-loaded plunger was selected by the lateral movement of the brake ring, and this provided an indication when operated on the control panel that the brake was 'OFF' attached to the liquid spring tie bar by extinguishing the indicator light. The microswitch was mounted on a bracket.

The liquid spring absorbed the braking loads applied by the brake mechanism and was rigidly braced to its anchorage on the side frame by a tie plate, which

counteracted the loads imposed and prevented any deflection of the brake mechanism.

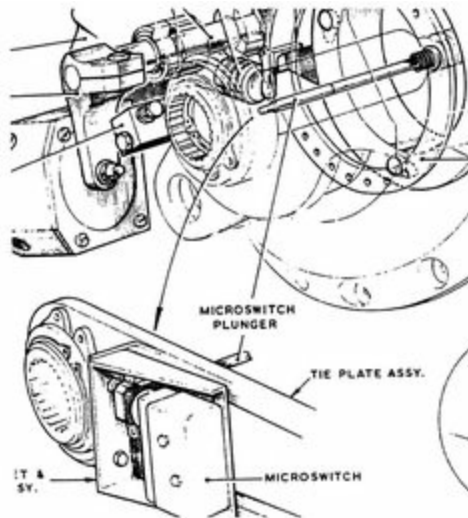


Fig. 223. Mk 20 hose-drum brake microswitch

In the hydraulic operation of the mechanism, when the brake solenoid was energized (see Fig 222) the spindle of the pilot valve moved forward and the ball at its free end was forced against its pressure seat, thus preventing fluid under pressure from entering the reset piston chamber. At the same time the pressure in that chamber was released to the return line via the ball valve. Fluid under pressure acted upon the release piston, and both pistons moved across to operate the power ring and release the emergency brake. When the solenoid was de-energized, the pilot-valve spindle was withdrawn from its seat. Hydraulic pressure forced the ball against the return set, and pressure now acted on both pistons. The pressure on the larger (reset) piston forced the pistons across to move the power ring in the opposite direction, thus returning the latch ring to its original position.

An emergency air system (shown on the hydraulic diagram) comprised two steel air bottles mounted in the rear

fairing of the pod (Fig 224), on the port and starboard sides of the fairing structure respectively. These were interconnected by rigid and flexible pipe lines to the inlet (air bottle) connection of an explosive valve (Fig 225) mounted on the starboard side frame of the hose-drum unit. A pipe line connected to the outlet connection of the valve conducted air under pressure via a shuttle valve to a reducing union connection on the brake-mechanism housing, to operate the hydraulic mechanism and thus release the emergency brake in the event of a hydraulic failure.

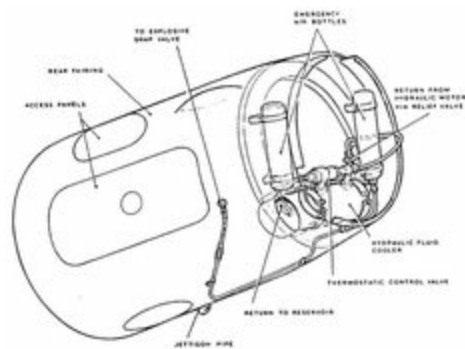


Fig. 224. Mk 20 hose-drum unit emergency brake air system

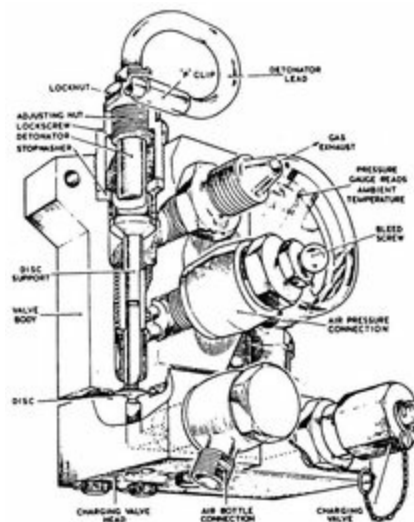


Fig. 225. Mk 20 hose-drum unit emergency air valve

The emergency-brake air valve was a Type SAV117-009 snap valve, having a detonator and frangible pillar assembly fitted in the valve's body prior to flight. In the event of a hydraulic failure the detonator was fused electrically by the selection of 'EMERGENCY TRAIL' on the pod's control panel.

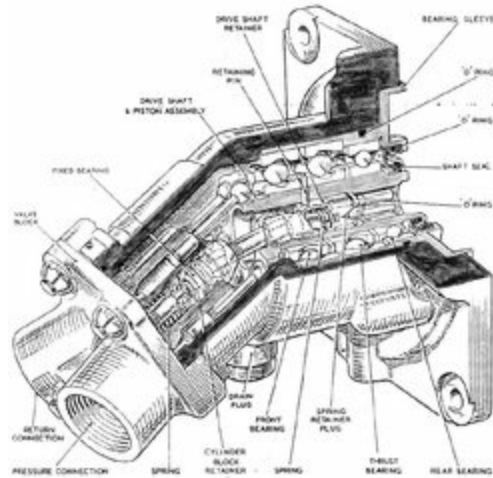
The supply of hydraulic pressure to the brake mechanism came from the main pressure-relief valve, which controlled the overall system pressure, and teed off this line was a pressure-reducing valve to supply hydraulic pressure to the brake's liquid spring at a reduced pressure, thereby ensuring that it was permanently charged during an operation.

Adjacent to the brake-mechanism hydraulic supply line, a high-pressure line was teed off to connect with the gear-change selector on the hose-drum-drive gearbox.

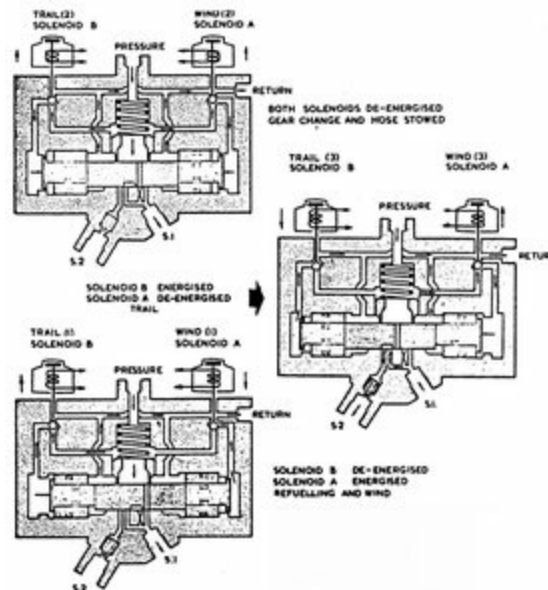
Similarly, downstream of the main pressure-relief valve a high-pressure line was connected to a hydraulic control valve, which controlled the hydraulic supply to the hose-drum driving motor.

The hose-drum drive assembly comprised a hydraulic motor and two-speed gearbox secured together and mounted on the tie plate at the aft end of the hose-drum-unit structure. The motor ([Fig 225](#)), a Vickers MF-36-024-B006GB3, was supplied with fluid from the power unit, the supply being regulated to 3,500 psi (238 bar) by the system's main relief valve and routed through a control valve (originally two valves were required, but later units these were amalgamated into one), which was located upstream of the motor. The drive to the motor was taken via a quill shaft to the gearbox and thence to the main drum driving chain.

Fig. 226. Mk 20 hose-drum driving motor



The motor could function as a motor and a pump according to the hydraulic fluid path dictated by the position of a sliding valve within the control valve ([Fig 227](#)).



[Fig. 227](#). Mk 20 hose-drum-unit drive-motor control valve

The valve had three hydraulic ports: one was the supply port, while the others were outlet ports, one having a throttling valve incorporated to control the hydraulic fluid flow during the trailing sequence, and the other a larger

bore for the winding sequence.

When the hydraulic motor was required to operate the hose drum, the electrohydraulic control valve controlled the direction of the hose-drum rotation. The valve incorporated a sliding piston assembly which opened or closed ports to the pressure and return connections of the hydraulic motor. The pistons were placed at opposite ends of the sliding valve, and both were of equal diameter; the hydraulic fluid flow to the pistons was direct from the main hydraulic supply at all times, and the supply to the pistons was controlled by two solenoid valves.

When both solenoids were de-energized, the hydraulic pressure on both pistons was equal and the sliding valve was centralized, providing a restricted flow to the motor. When Solenoid 'A' (wind port of valve) was energized, the pilot valve closed a fluid passage to prevent hydraulic pressure acting on the piston immediately below the solenoid, and hydraulic pressure acting on that piston was released to the return line. Solenoid B (trail port of the valve) remained de-energized, and hydraulic pressure continued to exert pressure on the piston immediately below that solenoid, which caused the sliding valve to move towards Solenoid 'A' and opened a passage to allow full hydraulic fluid flow to the motor inlet, so that the hose-drum motor would wind the refuelling hose in.

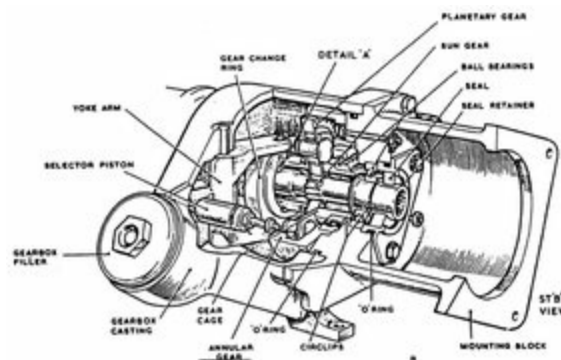
When Solenoid 'B' (trail port of the valve) was energized, the action above was reversed. In this instance, when the sliding valve had moved over towards Solenoid 'B', the supply pressure to the valve was blanked OFF, and the port to the throttling valve to the outlet side of the hose-drum drive motor was uncovered and hydraulic fluid passed through the throttling valve. It passed through the motor, which was now acting as a pump under this condition, the hydraulic fluid circulating around a closed circuit comprising the control valve, the throttling valve and the motor. This condition allowed the refuelling hose to trail under a

controlled speed.

The amount of hydraulic fluid circulating was governed by the throttling valve, which was spring-loaded to the 'OPEN' condition; the valve would therefore tend to close with increasing pressure. Since the hydraulic motor was operating in the 'TRAIL' sequence the hose drum rotated in that direction at a speed governed directly by the amount of fluid that was passed through the throttling valve. Excessive 'TRAIL' speeds, which would tend to rotate the motor faster and increase the pressure, would also cause the throttling valve to close partially, except in the case of a hydraulic failure within this closed circuit.

The gearbox ([Fig 228](#)) and parking brake was mechanical in operation, but its gear-change mechanism was actuated hydraulically. It provided two gear ratios, a direct drive from the coupling shaft of the hydraulic motor to the drive shaft of the gearbox, providing high gear, and a geared drive in which the drive was taken through an epicyclic 6.5:1 reduction gear to the drive shaft, providing a low gear.

Fig. 228. Mk 20 hose drum two-speed gearbox



The gear change was effected by the action of a solenoid-operated pilot valve that diverted fluid to a piston in the gear-change selector assembly. The reciprocating motion of the piston was applied to a pivoted yoke arm in the gearbox,

which acted on a spring-loaded engaging ring (Fig 229)

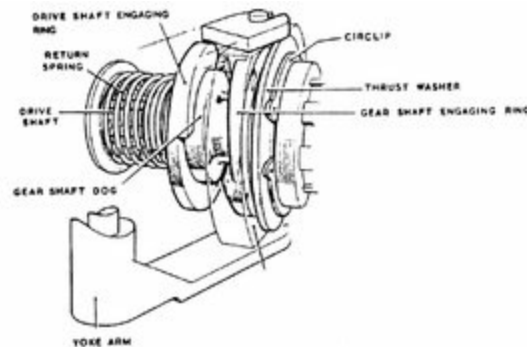


Fig. 229. Mk 20 hose-drum unit gearbox selector yoke

The hydraulic gear-change selector formed a separate component attached externally to the gearbox body, and controlled by a solenoid pilot valve (Fig 230).

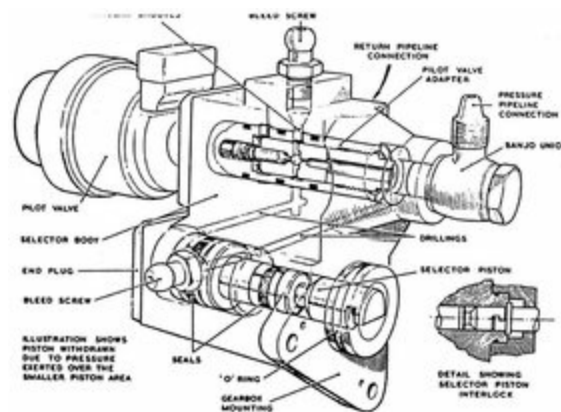


Fig. 230. Mk 20 hose-drum unit hydraulic gear-change valve

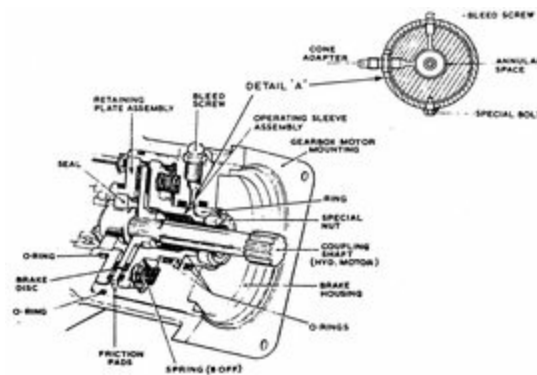
When the pilot-valve solenoid was de-energized the valve spindle withdrew, and hydraulic fluid pressure forced the ball valve against the return seat; the pressure now acted on both sides of the piston, and, since the pressure exerted over the larger area of the piston would overcome that of the smaller area, the piston would move inwards (low gear was selected). The hydraulic fluid entered the cylinder above the

piston head via the pilot-valve pressure seat and radial drillings to the annular groove, and thence through a connecting drilling. When the solenoid was energized the valve spindle moved the ball valve forward on its pressure seat, thus preventing the hydraulic fluid under pressure acting on the larger area of the piston.

Hydraulic fluid from that part of the cylinder flowed via the connecting drilling, the return seat and an annular groove into the hydraulic return line. Simultaneously, pressure acted via the pilot valve bore and connected the drilling on the smaller area of the piston and moved it outwards (high gear selected).

Between the hose-drum hydraulic driving motor and internal gears, a gearbox parking brake was incorporated (Fig 231).

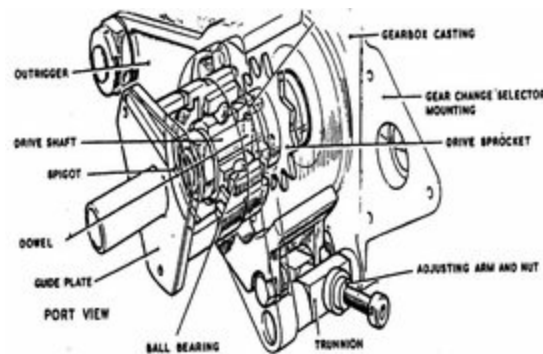
Fig. 231. Mk 20 hose drum gearbox parking brake



The parking brake was housed in the two-speed gearbox mounting for the hydraulic driving motor. The assembly comprised a cylindrical brake housing, flanged operating sleeve, brake disc and retaining plates; the sleeve flange and retaining plates were each lined with friction rings bonded to their inner faces. The sleeve was allowed approximately 0.060 inch linear movement in the centre bore of the brake housing.

Eight springs were equi-spaced and located between the brake housing, secured by a special bolt in the mounting block, and the operating sleeve; the springs seated in counter-bores of both components. Spring pressure exerted on the sleeve normally held the brake on to prevent rotation of the gearbox. When hydraulic pressure was applied to the annular in the housing, the sleeve moved away from the brake disc compressing the springs, allowing the gearbox to rotate.

Attached to the drive end of the gearbox was the hose drum's driving-chain sprocket ([Fig 232](#)), this assembly having a chain adjuster to maintain the correct tension.



[Fig. 232](#). Mk 20 hose-drum drive sprocket

The port hub of the drum ([Fig 233](#)) housed a rotary seal that connected the fuel-supply pipe and fuel flowmeter from the fuel-tank.

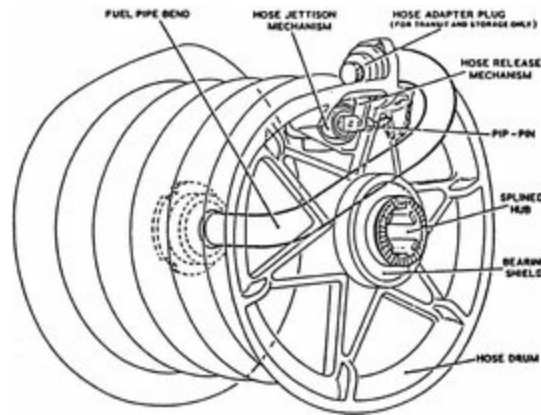


Fig. 233. Mk 20 hose drum

Also contained in the hose drum was an electrical slip-ring that was connected to a hose-jettison mechanism, which was similar in design and operation to that employed on the Mk 16, Mk 17 and Mk17B refuelling packages, as shown in [Fig 234](#).

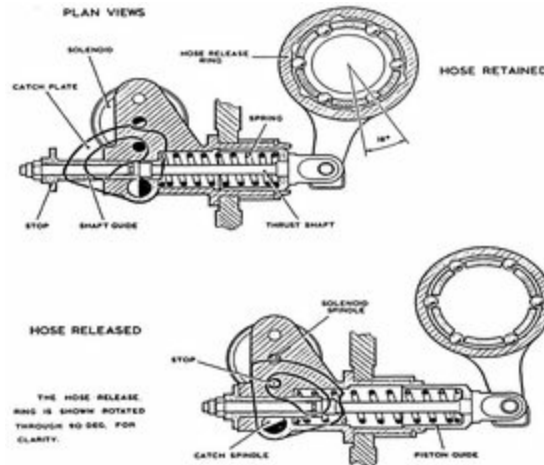


Fig. 234. Mk 20 hose-drum jettison mechanism

Also mounted on the port side frame was the speed-control unit ([Fig 235](#)) that was employed in the hose-drum brake circuit and applied the emergency brake if the refuelling-hose trailing speed exceeded 5-8 ft/sec.

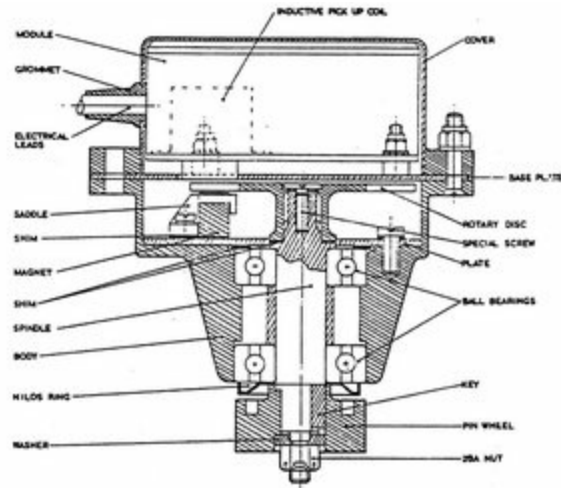


Fig. 235. Mk 20 hose-drum speed-control unit

The control unit was driven via a pin wheel that engaged the hose drum's main-drive chain sprocket. Attached to the other end of the pin-wheel spindle was a disc incorporating six equidistant peripheral cut-outs. As the hose drum rotated, the disc was also rotated by the pin wheel, and its periphery moved between a permanent magnet housed in the unit's body and an inductive pick-up coil mounted in the cover. The coil formed a part of an electronic module secured inside the cover, and as the disc rotated, the cut-outs in its periphery allowed the magnetic field to cut the turns of the coil, thus producing a succession of electrical pulses, the frequency and amplitude of which were dependent on the disc speed, i.e. hose trailing speed. The pulses were fed into a direction-sensing circuit that formed a part of the electronic circuit module. In the 'Trail' direction only, these pulses were made to trigger a two-second timer circuit, which in turn energized a relay interrupting the brake solenoid circuit and applying the brake.

To complete the hydraulic operational system, the remaining component was the ram-air turbine control system. The hydraulic supply for this was taken from the hose-drum drive-system supply being teed off to a turbine

selector valve and reducing valve, these being located on the rear bulkhead of the fuel-tank. A supply pipe from the selector valve to the turbine inlet connection, and a return pipe drain back to the selector valve, were accommodated in the narrow fairing above the fuel tank, together with the main delivery and return pipes. A stop valve, mounted accessibly on the top of the power-unit gearbox, was interposed in the return line. This valve allowed a restricted hydraulic flow to retard the turbine rotation in normal flight, and full flow in the reverse direction, for the refuelling operation. The valve was provided with a push-button for ground test purposes, which when depressed by an operating lever cut off all the flow through the unit. The push-button was depressed by the operating lever, which also operated a microswitch in the electrical supply to the turbine selector valve solenoid. The supply was broken when the button was depressed, thereby preventing the operation of the solenoid and the application of full hydraulic pressure to the turbine while the stop valve was closed. This prevented an excessive build-up in the turbine during ground testing, which might otherwise cause damage to the turbine pressure chamber and leakage past the seals.

To change the pitch of the ram air turbine blades, it was necessary to route a hydraulic supply line at a reduced pressure to the turbine. Operating pressure was derived from the main system, the supply line was tapped at a point between the relief valve and control valve; a return to the main system was tapped into the return line to the reservoir at the outlet side of the thermostatic valve on the oil cooler. The supply of 3,500 psi (238 bar) was connected to the turbine selector valve (Fig 236) servo connection P2 (the port on the left-hand side of the valve) to operate its sliding valve, and thence to the high-pressure connection of the turbine reducing valve; this valve reduced the hydraulic pressure for the operation of the turbine through the pressure connection at P1 (at the bottom of the valve) of the selector valve.

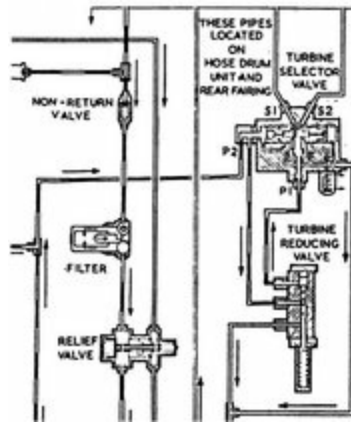


Fig. 236. Mk 20 refuelling-pod ram-air turbine selector-valve

When the turbine selector-valve solenoid was de-energized, the pilot-valve plunger retracted to open the port in the fluid passage and allowed hydraulic pressure at 3,500 psi (238 bar) to be exerted on both pistons of the sliding valve in the selector. Since one of the pistons was larger than the other, pressure was exerted on the larger piston with a greater force, thus pushing the sliding valve to 'open' a port and allowing reduced fluid pressure to flow via P1 through the selector to the service connection S1 (top left-hand side of valve), and opening S2 to the return line. From S1 fluid was routed through the stop-valve restrictor, which again reduced the

pressure, to the drain connection of the turbine to permit feathering and retarded rotation. The fluid returned to the main return line through the turbine inlet connection S2 (top right-hand side of valve) of the selector, whence the fluid was bypassed to the return line.

When the turbine selector-valve solenoid was energized, the pilot-valve plunger extended to close the port in the fluid passage and allowed hydraulic fluid at 3,500 psi (238 bar) to be exerted on the smaller piston of the sliding valve in the selector; the passage to the larger piston cylinder was closed by the pilot-valve plunger, but the fluid from the cylinder

could flow to return. The sliding valve was now pushed over and allowed fluid from the service connection S1 (top left-hand side of valve) to flow to the return line also, and fluid at reduced pressure from P1 (bottom of valve) was routed to S2 (top right-hand side of valve), and thence to the turbine inlet to coarsen the blade pitch. Fluid issued from the drain connection to return, passing through the stop valve, where a valve opened to bypass the restrictor, to the connection at S1 (top left-hand side of valve) of the selector, and thence to the main return line. Energization of the turbine selector-valve solenoid was effected when the master switch on the control panel was selected 'ON'.

The electrical system of the refuelling pod would take pages of detailed description. However, to cover this it is necessary to describe some of the component assemblies, together with their contents, and finally the operational sequence of air refuelling.

The relay box ([Fig 237](#)) contained all the relays concerned with the operation of the pod's circuits except for the fuel control relay, which was mounted in the control panel, and the lighting control relay, which was mounted in a separate box in the rear fairing.

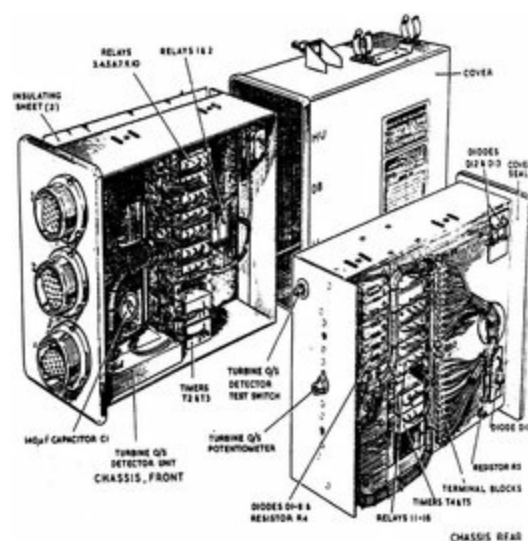


Fig. 237. Mk 20 refuelling-pod electrical relay-box

The relay box also contained the electronic timer units, ram air turbine overspeed detector unit and the test switch and potentiometer associated with the latter. All the relay-box components were mounted on a chassis assembly removable cover. Fifteen relays were mounted in the relay box, all being sub-miniature Clare or Ericson type. All the relays with the exception of two were mounted back-to-back in two banks, one of seven relays, the other six, on relay support bars attached to the chassis side plates. The remaining relays Nos 1 and 2 were mounted directly to the chassis plate. Four timer units were also mounted on the relay support bars, two on one relay bank and two on the other. The individual timers were encapsulated in an epoxy-resin compound, and connection to the relay-box wiring was by soldered joints. The numerous negative earth-return connections from the relays, etc., were made by a common earth connection provided by a 12-way miniature terminal block mounted on the chassis adjacent to the relay banks. Eight of the diodes associated with the relay supply circuits were mounted, with a resistor in the turbine overspeed detector circuit, on a component board attached to the chassis.

The turbine overspeed detector-unit was an epoxy-resin-encapsulated unit attached to the chassis. Associated with the detector unit were a potentiometer and a test switch. These were mounted on the rear end-plate of the chassis and projected through apertures in the rear wall of the relay-box cover. The unit was designed to illuminate a warning lamp if the turbine speed exceeded 9,000 rpm. The DC output from a tachometer generator coupled to the fuel-pump drive shaft in the power unit was applied to the overspeed detector unit, the 28 V supply to the detector unit was routed via a RED warning lamp on the control panel and operation of the detector completed the earth return path for the lamp

circuit.

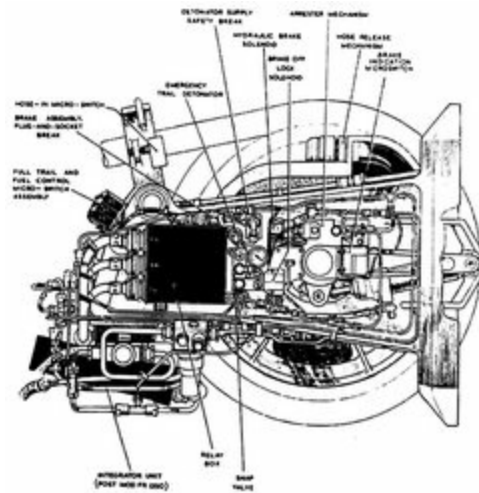


Fig. 238. Disposition of electrical components, starboard side

The disposition of the refuelling pod's electrical components, together with some of the other operational components already described, will now be illustrated. Those located on the starboard side of the hose-drum unit are shown in [Fig 238](#).

The main electrical component on this side of the hose-drum unit was the relay box. However, on the port side ([Fig 239](#)) there were some components that have not yet been described.

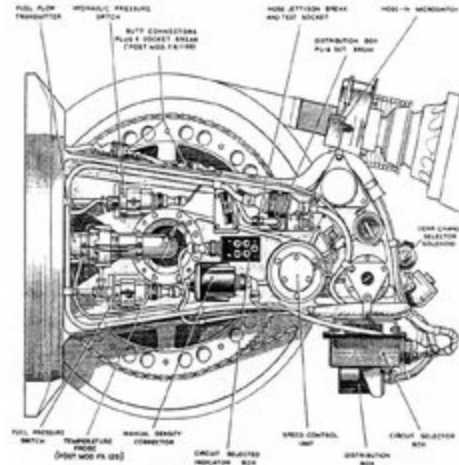


Fig. 239. Disposition of electrical components, port side

The electrical distribution box (Fig 240) was located on the hose-drum unit's aft tie beam on the starboard side. The box comprised a circular lid to which all of the components were attached. The associated hose-drum-unit wiring was led to the box via four gland-entry connectors. The electrical leads from the refuelling pod's electrical butt connectors also were routed to the box.

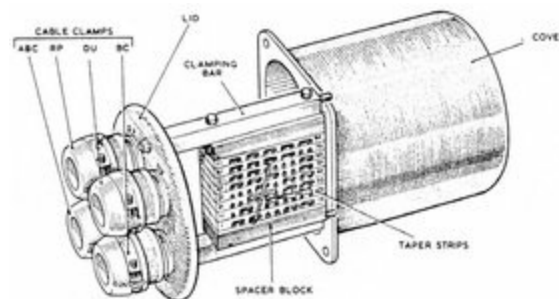


Fig. 240. Mk 20 electrical distribution box

The circuit selector box (Fig 241) was also located on the aft tie beam, and contained a 9 Wafer Ledex type selector-switch mounted to a mounting plate within the box. The switch can be described as the main distributor by means of which the 28 V DC supplies to the various electrical

components in a complete cycle of pod operation were provided at the appropriate time and in the correct sequence.

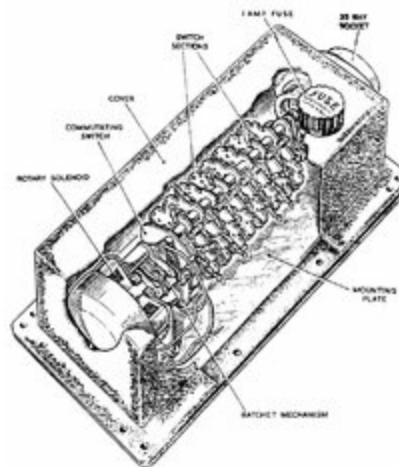


Fig. 241. Mk 20 electrical circuit-selector box

The circuit selected indicator box (Fig 242) was located centrally on the port side frame, and consisted of a small light-alloy box in the cover of which were five miniature indicating lamps, and a 6-pole fixing plug.

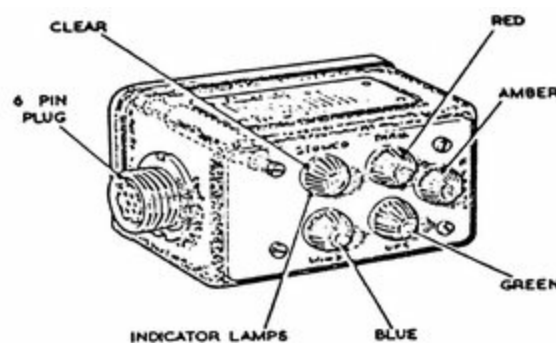


Fig. 242. Mk 20 circuit-selected indicator box

The five lamps were of a different colour and indicated the various stages of a refuelling operation during ground

testing. The colours, when illuminated, indicated as follows:

HOSE STOWED	White
TRAIL	Red
FULL TRAIL	Amber
OPS (refuelling)	Green
WIND	Blue

The lamp filaments could be changed without removing the box's cover, simply by unscrewing the coloured cap and then extracting the filament.

The fuel flow transmitter type EF 61114, together with its manual density type EF 86660, were located on the side frame, and the former's integrator unit type 7808-10000 was on the aft tie beam of the unit.

The other units on the side frame were the hydraulic pressure-switch and fuel system pressure-switch.

The rear fairing of the refuelling pod was provided with a detachable fairing to cover the hose-drum unit, and mount various equipment and to stow a collapsible drogue.

The structure comprised two separate components –the main fairing and a quickly detachable end fairing, as shown in [Fig 243](#). The main fairing was constructed with a pair of longitudinal panel sections providing a streamlined contour; which were butt jointed and strap riveted together on a vertical centre plane. The structure was stiffened at the rear end with a flanged frame, to which was riveted a support plate, located segmentally at the bottom of the frame, for mounting the hydraulic oil cooler.

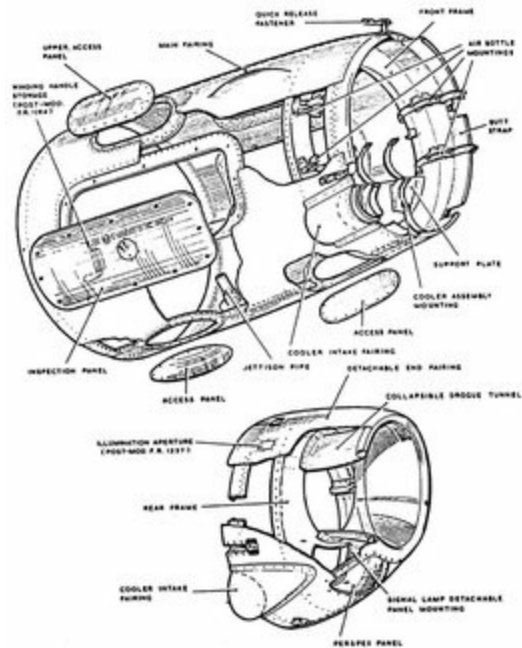


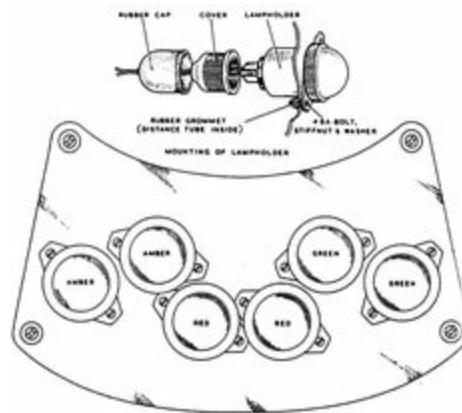
Fig. 243. Mk 20 refuelling pod rear fairing

A small fairing inserted at the top front edge of the main fairing allowed hydraulic pipes from the power unit to pass to the hose-drum unit, and a cooler intake scoop was inserted at the rear of the port-side skin panel, to mate with a similar scoop in the end fairing.

The streamlined contour of the end fairing was a continuation of that of the main fairing; it was similarly constructed and terminated at the circular entrance of a tunnel. The fairing was strengthened by one flange frame, canted to support the inner end of the tunnel. This end of the tunnel was riveted to the edge of a circular aperture eccentrically located in the upper face of the frame; the entrance of the tunnel was belled out and the lip welded to a stout tubular ring, to which also the skin panels were riveted. The tunnel was inclined downwards to allow the drogue to open and collapse correctly as the hose was trailed.

A small detachable panel, on which a double row of six

rearward-facing contact lights was mounted ([Fig 244](#)), was secured to the front face of the end fairing frame, the lamps protruding through a flanged aperture; the latter was located directly below the tunnel aperture in the frame, so that the lamps were visible to the receiver aircraft through a perspex panel framed in the skin panels below the drogue tunnel. Looking forward from the rear end of the refuelling pod the contact lights were arranged with two AMBER lights to the port side, two RED stand-off lights at the centre, and the two GREEN lights on the starboard side.



[Fig. 244](#). Mk 20 refuelling pod contact lights

The refuelling hose ([Fig 245](#)) was nominally 50 feet (15.4 metres) in length, and had a 1½-inch-diameter (38 mm) bore, with an external diameter of 2-inches (50.8 mm). The hose was made of fuel-resistant rubber, steel wire reinforced and sheathed overall in rubber. At each end it carried a special adapter: at the hose-drum end the adapter was grooved externally to mate with the hose-drum unit's hose-release mechanism, and the other was designed to accept the Mk 8 reception coupling. The whole length of the hose was unpainted except for fluorescent coloured bands at intervals to enable the pilot of the receiver aircraft to check how much hose was trailed at any moment, and thus judge the distance between the tanker and receiver aircraft when

The reception coupling (Fig 246) was similar to that employed on the Mk 16, Mk 17, and Mk 17B refuelling packages, with the exception that the bore through the coupling's ball-joint was smaller in diameter, and the coupling provided interchangeability with the American MA.2 refuelling equipment.



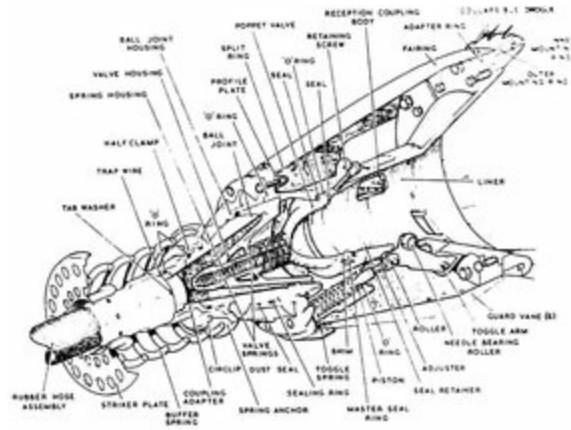
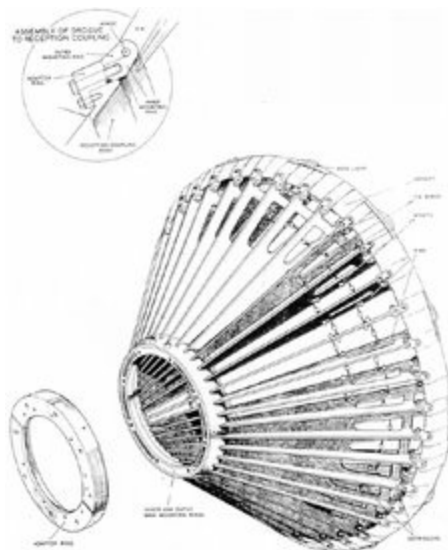


Fig. 246. Mk 8 reception coupling

The prototype and early Mk 20 refuelling pods incorporated a metal ventilated drogue similar to that employed on the Valiant tanker, but a smaller version. When the collapsible drogue entered service on the Valiant a smaller version was designed for the Mk 20 series of refuelling pods, as shown in Fig 247.

Fig. 247. Mk 20 refuelling pod collapsible drogue



The control panel for the Mk 20 series of refuelling pods (Fig

248) was designed for single-seat fighter aircraft, which would require the minimum of selections for a refuelling operation.

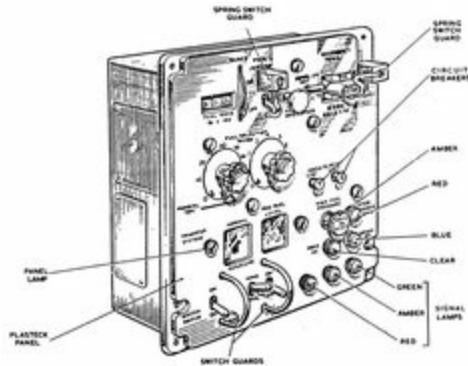


Fig. 248. Mk 20. Refuelling Pod Control Panel

The control panel consisted of a light-alloy box, to the lid or front panel of which were attached all the controls, switches, lamps, indicators, etc., concerned with the operation of the pod.

Illumination of the instruments and various labels and markings was by a 'Plastek' trans-illuminated panel attached to the front panel. The brightness of the panel lamps was controlled by a separate potentiometer in the tanker aircraft itself.

In addition to providing the means of remotely controlling a refuelling operation, the panel contained indicator and lamp equipment that gave visual progress of the operation and warned of any abnormal condition that necessitated emergency action. Such an emergency could be automatic, or might necessitate operation of further switchgear contained on the panel.

1. MASTER SWITCH. This switch was a two-position ON/OFF switch located at the bottom left-hand corner of the panel. It controlled the 28 V DC supply to all the pod circuits except for certain float-switch circuits, the

turbine overspeed detector circuit, and the hydraulic failure warning circuit.

2. FUEL-JETTISON SWITCH. This was a two-position, guarded ON/OFF switch located at the top of the panel; the guard had to be moved through 90 degrees before the switch could be moved to the ON position. In the ON position the switch caused the solenoids of the fuel-jettison valve and fuel selector to be energized, and the jettison and pressure-control-valve shut-off valves to be opened.
3. EMERGENCY TRAIL/HOSE-RELEASE SWITCH. This was a three-position, guarded switch with a central OFF position; it was located at the top right-hand corner of the panel. The guard had to be moved through 90 degrees before the switch could be set to either of its operative positions. In the EMERGENCY TRAIL position the switch completed the circuit to an explosive snap valve that admitted compressed air into the brake hydraulic mechanism and released the hose-drum brake and allowed the refuelling hose to be fully extended. In the HOSE RELEASE position the switch connected the DC supply to the solenoid of a jettison mechanism on the hose drum, but this was conditional upon the hose being at its full trail position.

In the HOSE RELEASE position the switch connected the DC supply to the solenoid of a jettison mechanism on the hose drum, but this was conditional on the refuelling hose being at the full trail position; in this instance the switch would release the hose without selecting EMERGENCY TRAIL.

4. REFUELLING LIGHT SWITCH. This was a two-position switch placed alongside the emergency trail/hose release switch; it was marked DAY and NIGHT and its function was to energize the lighting relay that caused the signal contact lamps to be dimmed when NIGHT was selected. The dimming was achieved by the introducing-series resistors in the lamp circuits.

5. TRAIL/WIND SWITCH. This was a two-position switch placed alongside the master switch. In the TRAIL position the hose-drum brake was released and the refuelling hose allowed to trail by the air drag on the drogue; the switch was left at the TRAIL position for the refuelling operation.
6. EMERGENCY SIGNAL SWITCH. This was a two-position ON/OFF switch placed alongside the trail/wind switch. It was used solely for signalling to the receiver aircraft, which caused the RED signal (contact) lamps to be illuminated, irrespective of other lamps that were illuminated at the time.
7. FUEL-SELECTION CONTROLS. Two calibrated selectors on the panel enabled the control-panel operator to preselect the weight of fuel that it was intended to transfer to a receiver aircraft. It was important that preselection was made before the master switch was set to ON. Each selector was a rotating switch connected electrically in the circuit controlling the fuel-selector valve. Passage of fuel to the receiver aircraft resulted in the transmission of electrical signals back to the selectors, which were rotated in an anti-clockwise direction. At any moment during the transfer of fuel the selectors thus showed a reading of the weight of fuel still to be transferred. Both selectors were calibrated to show fuel weight in lb x 100, the left-hand dial reading from zero to 80 and the right-hand reading from zero to 9. As an example of setting the selectors, if it was desired to pass 4,500 lb of fuel, the left-hand selector would be set to 40 and the right-hand selector to 5. At the completion of the operation, both selectors would have rotated anti-clockwise to show a dial reading of zero, and this would coincide with the automatic closure of the fuel-control valve. The left-hand selector had a MANUAL ON position by which the automatic shut-off function of the fuel supply was overridden, and fuel would pass until the switch was returned to zero. A reading would still be

available on the totalizer under this condition.

FUEL TOTALIZER. Indication of the quantity of fuel passed to the receiver was given by the totalizer mounted at the top of the panel. It gave a reading in lb x 100 of the weight of fuel transferred, visible in a window in the 'Plastek' panel. The counter could be reset to zero by a knurled wheel alongside the window. The totalizer was operated electrically by the same supply as the fuel selectors.

8. MAGNETIC INDICATORS. Two magnetic indicators were fitted to the control panel below the fuel-selection controls; each indicator was of the three-position type, showing a blank face when the indicator coils were in a de-energized condition.
 - a. NORMAL/REFUELLING INDICATOR. In the operative (energized) condition of the left-hand indicator an arrow appeared, pointing either upwards to NORMAL or downwards to REFUELLING, engraved on the panel. The purpose of this indicator was to remind the operator of the fuel-system condition of the tanker aircraft, i.e. whether the system was set for a refuelling operation with the pod delivering, or ready to deliver fuel to the receiver aircraft.
 - b. POD FUEL-LEVEL INDICATOR. The panel above the right-hand magnetic indicator was engraved POD FUEL LEVEL and the two operative positions of the indicator were inscribed MAX and MIN. MAX indicated the pod fuel-tank was at its maximum capacity, and it appeared when the high-level float-switch reached its highest position. Conversely, the indicator showed MIN when the fuel level in the tank was sufficiently low for the float of the low-level float-switch to drop to its lowest position. At any point between these extreme positions, the indicator showed a blank face on a falling fuel level. When the

level was rising after MIN was indicated, MIN would remain until the mid-level float-switch operated, and then the blank face was shown until the high-level float-switch operated.

9. WARNING LIGHTS. Eight warning lights were fitted to the panel to provide an indication of the progress of a refuelling operation and to give a warning of certain abnormal conditions such as excessive fuel pressure, overspeeding of the ram air turbine and hydraulic failure. The three lamps at the bottom of the panel were connected in parallel with the contact lights on the rear of the pod rear fairing and provided confirmation to the operator that the correct signals were being displayed,.
 - a. HIGH-PRESSURE LAMP. This showed an AMBER light when the fuel pressure in the delivery line was sufficiently high to have caused the pressure-switch fitted in the venturi sensing line to operate. This lamp incorporated a reset switch, which permitted the reopening of the pressure-control valve consequent upon closure; it was reset by depressing and holding the illuminated push-button for approximately two seconds.
 - b. HYDRAULIC POWER FAILURE LAMP. This showed a RED light whenever the hydraulic pressure supply had failed completely. The supply to the warning lamp was controlled by a pressure-switch in the hydraulic fluid line. The switch operated on a falling pressure of 2,800 psi (190 bar) and broke on a rising pressure of 2,700 psi (184 bar). The supply for the warning light was obtained directly from the tanker aircraft and thus gave a warning of low hydraulic pressure irrespective of the position of the master switch.
 - c. BRAKE 'ON' WARNING LAMP. This showed a BLUE light when the emergency brake was applied. It was not illuminated when the automatic mechanical

brake was applied at the full trail position. The lamp was supplied via a microswitch attached to the brake mechanism tie plate. The switch was operated by a spring-loaded plunger, which in turn was operated via the brake ring.

- d. HOSE-IN LAMP. This lamp gave a plain, uncoloured light when the hose was fully wound in on the hose drum, and flashed intermittently when the hose was wound in or out. It was electrically connected to two microswitches located on the serving carriage behind two spring-loaded plungers. A pressure plate was attached to the inner end of the buffer spring at the rear of the drogue when the hose was fully wound in. The buffer spring was compressed by the plate that actuated the switches. Either microswitch was capable of causing the light to be illuminated, but provision of two switches allowed for the hose end not stowing centrally in the serving carriage. In addition to this function the lamp was utilized to indicate that the hose was moving in either the wind or trail directions. The electrical supply to the lamp was derived from a hose-motion microswitch assembly attached to the starboard side frame, and actuated by a flat on the serving gear's Archimedean shaft.
- e. TURBINE OVERSPEED WARNING LAMP. This showed RED if the ram air turbine overspeeded. It was illuminated through the operation of the detector unit fitted in the relay box, and a tachometer generator housed in the turbine mounting of the gearbox.
- f. SIGNALLING LAMPS (contact lights). These formed the bottom row of three lamps, coloured RED, AMBER and GREEN. They were connected into the same circuits as the rearward-facing lamps, and a simultaneous signal could thus be displayed on the tanker aircraft control panel and to the receiver

pilot. Operation of the lamps was automatic, once a refuelling operation had commenced. However, the circuit to the RED lamps could be made by the manual operation of the emergency signal switch. The RED lamp was illuminated when the master switch was ON and TRAIL was selected, and the hose was being wound out or in. The AMBER lamp was illuminated only when the hose was at the full trail position (or full trail less 6 ft) and the high gear was selected; the GREEN lamp was illuminated only when a receiver aircraft had engaged the drogue and the necessary equipment had functioned to permit the passage of fuel from the tanker aircraft to the receiver.

10. CIRCUIT BREAKERS. Two circuit breakers of the press-to-reset type were fitted to the panel above the warning lamps. They were labelled C.B.1. and C.B.2. respectively, the former being of 7.5 A rating and the latter 5 A. Both circuit breakers were in the 28 V DC circuit, C.B.1. protecting the normal services within the pod and C.B.2. protecting the emergency services.
11. DIODES. The diodes employed in the circuit to the three signal lamps and the hose-in, brake-on and hydraulic-failure lamps were encapsulated in an epoxy-resin block located at the top rear of the front panel above the fuel-jettison switch. Connection to the relevant circuits was made via soldered leads emerging from the block.



Production line of Mk 20B refuelling pods, Wimborne

Overall functioning of Mk 20 series of refuelling pods

Until the tanker aircraft reached a rendezvous and commenced the procedure for refuelling a receiver aircraft, the pod could be used as a drop tank as a part of the normal fuel system of the tanker aircraft. In this condition, fuel from the pod's fuel-tank was transferred to the wing and fuselage tanks of the parent aircraft by air pressure.

The pod's fuel contents could therefore be at any level between empty and full when the tanker aircraft made a visual contact with the receiver aircraft. By switching the master switch to 'ON', all the electrical circuits within the pod were completed, including the circuit to the pod's magnetic fuel-level indicator on the control panel.

The magnetic fuel-level indicator would show MAX only if the pod fuel-tank was full. In this condition, when the float high-level switch contacts closed, the low-level float-switch contacts opened and the circuit to the tanker aircraft's refuelling valve, which controlled the fuel flow into the pod's tank, was broken, whereupon the valve closed.

When the transfer of fuel from the pod to the receiver commenced, the fuel level within the tank fell, and the high-level float-switch contacts opened, which cancelled the MAX

indication on the fuel-level indicator. At the same time the low-level float-switch closed to restore the circuit to the tanker's refuelling valve, which opened to admit further fuel into the pod's fuel-tank.

When the master switch was switched to ON, the possible state of the fuel-system indications on the control panel could be as follows:

1. Fuel-tank full-tanker aircraft refuelling valve closed and MAX shown on magnetic indicator.
2. Fuel-tank empty-tanker aircraft refuelling valve open and MIN shown on the magnetic indicator. Note: MIN would continue to be displayed until the mid-level float-switch was operated, when a blank indication would appear.
3. Fuel-tank level between full and empty-tanker aircraft refuelling valve would be open and the blank face would be displayed on the magnetic indicator.

With the master switch on, certain lamps would be illuminated on the control panel: the blue lamp indicated that the emergency brake was on, and the white lamp indicated the hose was fully wound in, the circuit to the lamp being completed by the hose-in microswitch. The red signal lamps on the control panel and on the rear fairing were not automatically illuminated until TRAIL was selected. However, a hydraulic failure, in addition to illuminating the red HYDRAULIC FAILURE warning light, would also illuminate the red signal lamps. Provision was made available for illuminating the red signal lights in an emergency via the manually operated EMERGENCY SIGNAL switch.

Before the refuelling hose was trailed, the quantity of fuel that was to be transferred was preselected on the panel's selector-switches. The effect of this selection was to maintain the electrical circuit to the fuel-selector-valve solenoid until both selector-switches had rotated back to

zero; when both switches were at zero the electrical circuit to the fuel-selector-valve solenoid was broken and the pressure-control valve closed. The switches were rotated by electrical pulses received from the fuel-flow integrator unit, which emitted a pulse as each 100 lb of fuel was passed. If a manual selection was made instead of the automatic preselection of a fixed quantity of fuel, the pressure-control valve would remain open while the appropriate selector-switch was retained in the MANUAL ON position; as soon as the switch was moved to its zero position the circuit to the fuel-selector valve was broken and the pressure-control valve closed.

The normal/refuelling magnetic indicator on the control panel was not connected to the pod. It was connected into the electrical circuit of the fuel-control system in the tanker aircraft, and indicated that the tanker fuel system was either set to use the pod as a pylon tank (NORMAL) or to let the fuel pass into the pod fuel-tank for a flight refuelling operation (REFUELLING). It was essential that REFUELLING was shown by the magnetic indicator before further selections were made.

To trail the hose, the wind/trail switch was selected to 'TRAIL'. The following sequence of operations was then initiated:

1. The selector-switch in the circuit selector box moved through two positions, since the closure of the wind/trail switch completed the 28 V DC circuit to the solenoid of the selector-switch.
2. The RED signal lights in the rear fairing and on the control panel were illuminated, the circuit to the lamps being completed by Wafer 8 of the circuit selector switch.
3. Solenoid B of the hose-drum-drive hydraulic control valve was energized, and hydraulic fluid was diverted around the closed circuit formed by the control valve, the throttling valve and the hose-drum driving motor.

4. The 'brake-off' circuit was completed and the hydraulic brake system operated to release the brake and gearbox parking brake. At the same time the blue 'brake-on' light on the control panel was extinguished.
5. With the brake released, the reception coupling buffer-spring exerted pressure against the serving carriage to force the drogue into the tanker aircraft's slipstream sufficiently for the drag on the drogue to pull the refuelling hose off the hose drum. The hose commenced to unwind, the 'hose-in' microswitches on the serving carriage, which were closed when the hose and drogue were wound in, were now open, and the circuit to the white lamp on the control panel was broken.
6. During the trailing sequence, the white light was illuminated intermittently by the action of the hose-motion microswitch. The supply was applied via the microswitch contacts and a 22 ohm resistor, to charge up a bank of capacitors. Each revolution of the Archimedean shaft cam caused the microswitch to change over, and the capacitors were discharged through the lamp. A diode in the 'hose-in' microswitch supply to the white lamp prevented the capacitors discharging through the selector-switch solenoid via Contacts 9 and 12 of Wafer 3 and causing inadvertent operation of the selector-switch.

The drag effect on the drogue would continue to unwind the refuelling hose from the drum, the hose speed being governed by the throttling valve in the hose-drum-drive hydraulic control valve. When the fully trailed position was reached, the two 'FT' microswitches on the switchgear assembly located on the aft end of the starboard side frame of the hose-drum unit were closed. Microswitch F2 operated simultaneously with F1, and was connected in the hose-jettison circuit to ensure that the hose could not be released until it was fully trailed. The following sequence of operations took place when the hose reached the fully trailed

position:

1. The full-trail microswitch closed to complete the 28 V DC supply to the selector-switch solenoid and the switch rotated through two more positions. The gear-change solenoid was now energized via Wafer 6 and high gear was engaged. The mechanical operation of the gearbox caused the high-gear microswitch to close, completing the circuit for the selector-switch solenoid via Wafer 4, and the switch rotated two more positions.
2. The supply to Timer T2 was completed via Wafer 5, and after a delay of two seconds, Relay 9 was energized to complete the supply to Solenoid A of the hose-drum driving-motor control valve. Simultaneously Relay 1 was energized to interrupt the supply to Solenoid B of the control valve. At the same time, the contacts of Relay 9 closed to complete the circuit for the amber warning lights in the fuel control system. The RED warning light lamps' circuit was broken at Wafer 8 and the lamps were extinguished. Solenoid A remained energized during the refuelling operation. The delay in energizing Solenoid A was introduced to ensure that the gear change-over had been completed before full hydraulic pressure was applied to the hose-drum driving motor. When the refuelling hose was fully trailed and the 'AMBER' contact lamps were illuminated, the receiver proceeded to engage the reception coupling. When a successful engagement had been achieved, the following operations took place:
 - a. The refuelling hose was wound in for a distance of 5-7 feet as the receiver closed in after engagement.
 - b. The serving carriage moved away from the switchgear assembly on the starboard side frame and the fuel microswitch, FC, closed, completing the supply, via a timer, T4, to operate the coil of Relay 2. After a delay of two seconds Relay 2 was energized, completing the supply to the fuel-selector-valve Relay 11, which now operated to energize the fuel-

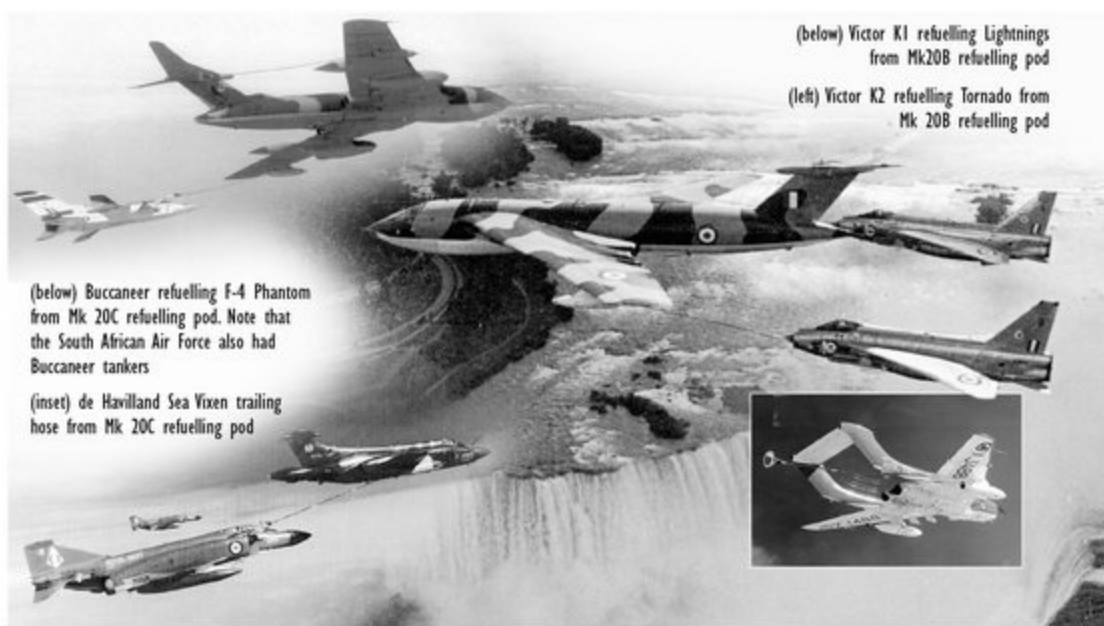
selector valve, at the same time extinguishing the AMBER contact lights and illuminating the GREEN contact lights. The delay in opening the fuel-pressure control-valve after the fuel microswitch had operated was to allow time for the probe nozzle of the receiver aircraft to enter and lock in the reception coupling properly before fuel transfer commenced.

- c. Fuel passed from the pod's fuel-tank to the receiver aircraft and the flow of fuel was monitored by the flow transmitter. This instrument transmitted signals to the integrator, which in turn sent out pulses to the fuel-selector relay in the control panel. For each 100 lb of fuel transferred, the integrator transmitted one pulse. This process continued until the fuel-selector switches had both returned to zero, at which point the circuit to the coil of No. 11 relay was broken. The relay was now de-energized and the pressure-control valve closed; simultaneously the GREEN contact lights were extinguished and the AMBER contact lights illuminated.
3. When the desired amount of fuel had been passed to the receiver aircraft, contact between the aircraft was broken by a reduction in speed of the receiver aircraft. The operator then selected 'WIND' on the control panel wind/trail switch, which initiated the following sequence of operations:
 - a. The circuit selector switch was energized via Wafer 2 and the switch rotated through two positions, extinguishing the AMBER contact light and illuminating the RED stand-off contact lights. (Wafer 8). Solenoid A of the hydraulic-motor driving valve was de-energized and Solenoid B was energized momentarily via Relay 1 contacts. After a 0.5-second delay the gear-change solenoid and Solenoid B were de-energized and low gear engaged. After a further delay of two seconds, Relay 9 was again energized,

completing the supply to Solenoid A, which was also energized.

- b. The hydraulic supply was therefore restored to full flow and maximum torque at the hose-drum driving motor was available for winding in the refuelling hose. The purpose of holding the hydraulic supply at its reduced flow until low gear was engaged was to prevent the application to the hose drum of the sudden torque load caused by the combination of low gear and a hydraulic supply at full flow.
- c. A temporary pressure loss occurred when WIND was selected, and caused the hydraulic failure warning light to come on, but as soon as the refuelling hose commenced to move, the white 'hose-in' indicator lamp flashed intermittently to indicate hose movement.
- d. When the refuelling hose was completely wound in, the two 'hose-in' microswitches on the serving carriage were closed and the 28V d.c. supply was connected through them and to the selector-switch solenoid. The selector-switch rotated two positions and then, because the wind/trail switch was still at WIND, the supply at contact 11 of wafer 2 maintained the switch solenoid in the energize condition and the switch rotated through two more positions, back to its original starting position ready for the next cycle of operations. The 'hose-in' microswitches also completed the circuit for the 'hose-in' indicator. The hydraulic warning light went out when the hose was stowed.
- e. Simultaneously with the closure of the microswitches on the serving carriage and the consequent movement of the selector-switch, solenoid A on the hydraulic driving motor control valve was de-energized and hydraulic fluid was routed through the restrictor, thus reducing the fluid flow. In addition the brake circuit was interrupted and the brake

mechanism operated to apply the brake. The white and blue lamps on the control panel were illuminated, the blue light indicating that the brake had been applied and the white light that the refuelling hose had been stowed. When the master switch was moved to the OFF the ram turbine selector valve solenoid was de-energized and the turbine blades moved to fine pitch to reduce the hydraulic pressure on the pod's circuit, the reduced pressure caused the gearbox parking brake to be applied.



CHAPTER TWENTY-THREE

Handley Page Victor

K1 Tanker Aircraft



Handley Page prototype Victor three-point tanker XA.918

In November 1963 approval was given for the conversion of the Handley Page Victor B Mk 1 into a three-point tanker. Owing to the demise of the Vickers Valiant single-point tanker, some urgency was now required for its replacement, the Royal Air Force no longer having the capability of refuelling in the air; other than from the American KC.135 boom tankers.

The new tanker was to be equipped with a modernized version of the Mk 16 refuelling package, designated as the Mk 17 package, and two Mk 20B under-wing refuelling pods, a variant of the Mk 20A naval refuelling pod.

Initially, however, because of the urgency, six aircraft were converted to two-point tankers, as has been mentioned earlier. Nevertheless a total of seventeen, inclusive of the six

two-point, were to be converted. The following are the serial numbers of the aircraft, the first six being in the order of their conversion into Victor Mk 1 two-point tankers, which were designated as KP.

XH.620 1st conversion

XH.667 2nd conversion

XH.648 3rd conversion (now at
Duxford)

XH.647 4th conversion

XH.615 5th conversion

XH.646 6th conversion (last one converted prior to
full three-point).

Victor Mk 1/1A three-point tankers. Order of build uncertain, but sensibly as follows, from left to right:

XA. 937, XH.618, XA.928, XA.936, XH.587, XH.849,
XH.651, XA.939, XA.938, XA.936, XA.941

The first outline proposal for the supply of in-flight-refuelling equipment to satisfy the requirement of Air Staff Standard of Preparation No. 50 dated May 1962, and complementary to the Handley Page Design Study HP/PROV/PHW/8045 dated 24 September 1962, was Flight Refuelling Ltd's Report ENG/PSM/MPC/12593 dated 25 October 1962. This report summarized the proposed modifications to improve the Mk

16 refuelling package and the changes required for the aircraft systems' interfaces, thus designating the package as the Mk 17, and likewise redesignating the Mk 20A refuelling pod as Mk 20B.

Initially it was thought that the Mk 20A refuelling pod would remain a standard item, thus serving both the Royal Navy and the Royal Air Force with identical equipment. However, because the Victor's wing pylon had a differently positioned fuel line, this necessitated a modification, making the unit nonstandard with the Mk 20A. Also, the original design of the Mk 20A was for temperate zones only, and not for a long high-altitude role, as was discovered with the initial Victor two-point tankers. Further modifications were required to make the refuelling pod compatible with long low-temperature operations and world-wide operations.

The urgent need for the converted Victor led to the interim two-point tanker being released into service after a minimum time at A&AEE Boscombe Down. Early squadron flying included trials to obtain the fuel consumption and performance data at various airspeeds and altitudes for the new configuration.

The two-point tanker fuel system diagram is shown in [Fig 249](#), where the fuel lines are shown being tapped into the cross-feed engine supply line from the wing fuel proportioners via an isolation valve.

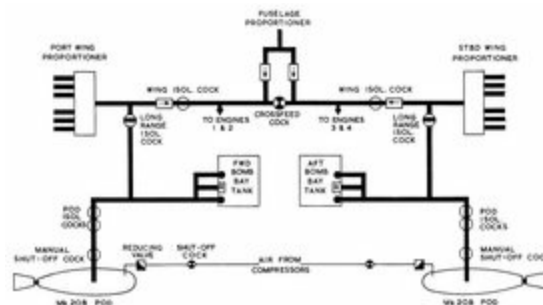


Fig. 249. Victor KP2 two-point tanker fuel-system diagram

Fuel was also taken from the additional forward and aft bomb-bay tanks by having five fuel pumps in each, and thence via isolation valves and a manual shut-off cock. These provided an extra 1,913 imperial gallons (8,608 litres) of transferable fuel in each tank. The pod's fuel tank was pressurized by air from the aircraft's air compressors via a shut-off cock and a pressure-reducing valve.

The Mk 20B refuelling pod was mounted to an under-wing pylon, as shown below.



Prototype Mk 20B refuelling pod on Victor KP2

The prototype Mk 20B refuelling pod employed the original Dowty Rotol Ltd ten-bladed constant-speed ram air turbine, as shown below, but eventually the R.AT/10/1 two-bladed 20-inch-diameter turbine replaced it.



Constant-speed turbine KP2 pod

The pod was suspended from each wing pylon, as shown in [Fig 250](#), via a machined sole-plate at the base of the pylon designed to the RAE Standard 2,000 lb pylon sole-plate ARM.E.84677, which provided dimensionally the positions of all the aircraft interfaces.

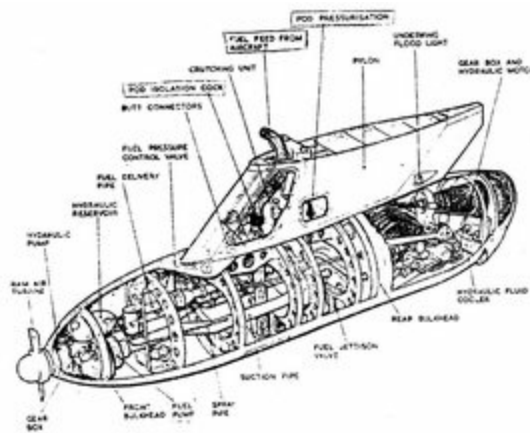


Fig. 250. Mk 20B refuelling pod and wing pylon

These included the fuel inlet, air-pressurization inlet, suspension point, two electrical butt connectors, and the forward and aft spigots to accept the various fore and aft and side loads from the pod. However, due to the fuel inlet line being of a larger dimension than that called for on the RAE design, a new fuel inlet was incorporated between the suspension point and the two electrical butt connectors. Within the pylon the suspension unit was a Frazer Nash ejector unit with the ejection system deleted, as the pod was not to be a jettisonable item. Nevertheless the unit accepted the crutching loads between the pylon sole-plate and the pod's structural members, thus preventing any movement of the pod in flight.

The two-point tanker filled the gap in the United Kingdom tanking requirements after the demise of the Valiant tankers, even though during their conversion the United States of America provided a temporary service with their

KC135 tanker with the boom drogue adapter.

Fig 251 shows the overall three-point-tanker fuel system with the Mk 17 refuelling package added. The probe for the aircraft to receive fuel was added earlier in the life of the aircraft, and the fuel during a receiving operation passed through a non-return valve aft of the probe's nozzle. The fuel line then joined the wing cross-feed ground refuelling line, also having teed into it a further line feeding fuel via a non-return valve. This latter line also had teed into it a line directly connected to the two bomb-bay fuel-tanks via refuelling valves. The two tanks were connected to the Mk 17 refuelling package, together with a branch line feeding to a cross-feed to the two Mk 20B refuelling pods. The bomb-bay pumps could also supply fuel to the fuselage fuel proportioner. Thus the overall system could supply the Mk 20B refuelling pods and the Mk 17 refuelling package from any fuel-tank within the aircraft's system, but mainly from the bomb-bay tanks, and at the same time for the aircraft's engines.

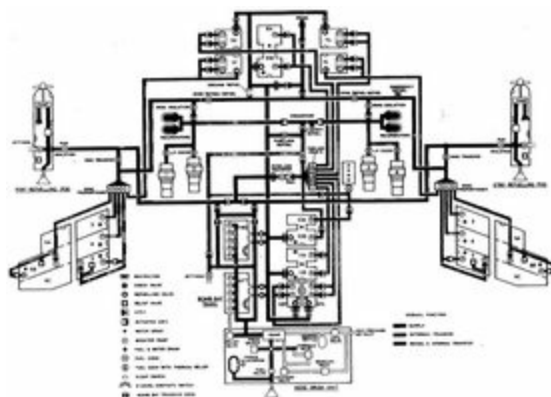


Fig. 251. Victor K1 three-point-tanker fuel system

The Mk 17 refuelling package was slung from a platform hinged to the roof of the bomb-bay aft of the bomb-bay fuel-tanks, and was partially enclosed by a fairing, as shown in Fig 252. The unit could be raised and lowered using the

aircraft's hydraulic system. When the package was lowered in preparation for air-to-air refuelling, the drogue was placed in the slipstream of the tanker and ram air intakes fed cooling air to the hose-drum driving motor, and the heat exchanger for the air from the aircraft engine compressor to drive the package's air turbine fuel pump, and for the oil cooler in the hose drum's oil system.

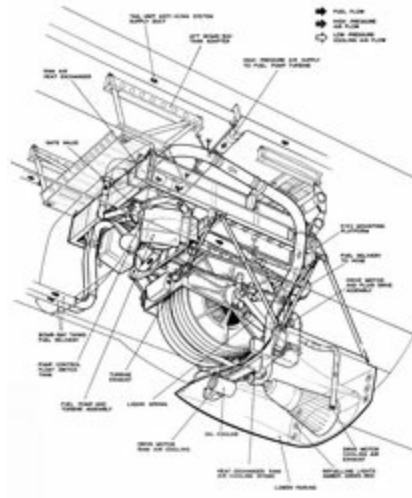
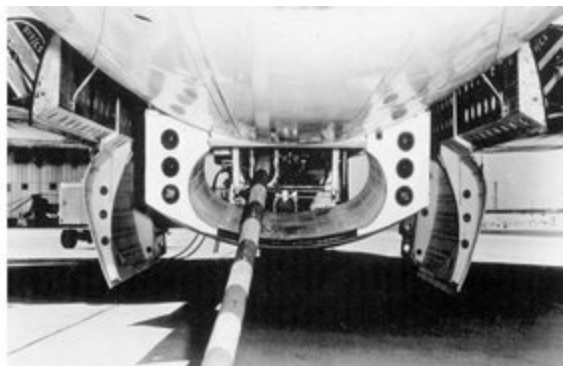


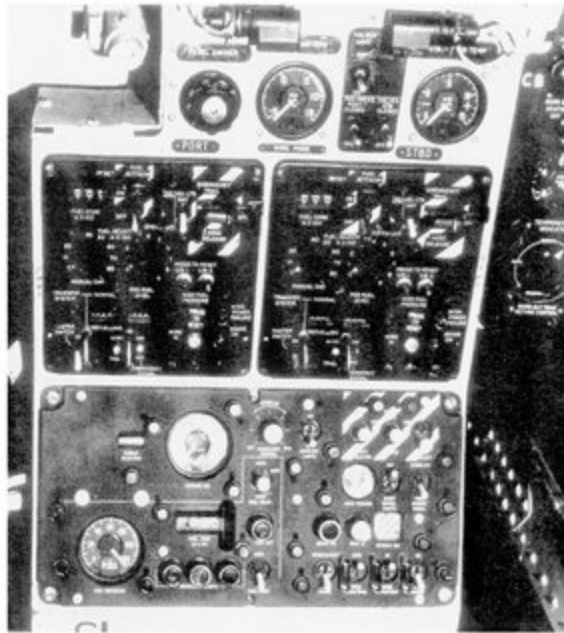
Fig. 252. Victor K1 Mk 17 refuelling package installation

The fairing housed the drogue when the hose was fully wound in. On the aft face of the fairing there were three pairs of contact lights, which were duplicated on the package's control panel, as shown below.



Victor K1 three-point-tanker fuselage contact lights

The control panels for the refuelling equipment were mounted together at the Nav-radar position, and the two Mk 20B panels were mounted above the Mk 17, as shown below.



Mk 20B and Mk 17 refuelling control panels

Operation of both the Mk 20B and Mk 17 refuelling equipment is described in their own sections.

The Victor three-point tanker was cleared to refuel the following aircraft in flight from the following aircraft stations using a high-speed drogue at 210-320 kts and a low-speed drogue at 180-230 kts:

Short Belfast	Fuselage only
Blackburn Buccaneer	Fuselage and wing pods

CF.5	Fuselage and wing pods
F.100	Fuselage and wing pods
Hawker Harrier	Fuselage and wing pods
Jaguar	Fuselage and wing pods
Lightning	Fuselage and wing pods
F-4 Phantom	Fuselage and wing pods
SeaVixen	Fuselage and wing pods
VC10	Fuselage only
Victor	Fuselage only
Vulcan	Fuselage only

Speed limitations, Mk 20B pod

1. Maximum trail and in-flight speed:
320 kts/0.88 M
2. Minimum trail and in-flight speed:
230 kts
3. Maximum in-contact speed:
290 kts/0.88 M (300 kts/0.88M for Phantom)
4. Minimum in-contact speed:

- 230 kts
5. Maximum hose-rewind speed:
275kts up to 35,000 ft decreasing linearly to 260
kts/0.855 M at 40,000 ft, 0.85 M above 40,000 ft
 6. Minimum rewind speed:
230 kts
 7. Recommended emergency:
200 kts up to 150,000 lb, trail speed increasing linearly
to 225 kts at 180,000 lb
 8. Recommended hose-jettison:
230 kts speed

Speed limitations, Mk 17 package (using the high-speed drogue)

1. Maximum trail and in-flight:
320 kts/0.88 M speed
2. Minimum trail and in-flight:
210 kts at sea level, decreasing speed. Linearly to 227
kts at 43,000 ft
3. Maximum in-contact:
320 kts/0.88 M speed
4. Minimum in-contact speed:
230 kts
5. Maximum hose-rewind speed:
320 kts/0.88 M
6. Minimum hose-rewind speed:
230 kts
7. Recommended emergency trail:
200 kts up to 150,000 lb, speed increasing linearly to
225 kts at 185,000 lb
8. Recommended hose-jettison:
230 kts speed

Low-temperature limitations

Between -50 and -58 °C IOAT (indicated outside air temperature), fuel transfer had to begin within 15 minutes of trailing the hose. On the completion of the transfer, the hose had to be rewound unless a further transfer was commenced within 15 minutes.

Receiving fuel

The Victor was cleared to refuel from the following tankers:

KC135:

By day only, up to 30,000 ft between 250 and 260 kts

Victor K1, K1A and K2:

By day and night up to 40,000 ft

CHAPTER TWENTY-FOUR

Vice Versa Air Refuelling

Vice versa air refuelling (1966)

The investigation made into reversing the roles of the tanker and receiver using the probe and drogue method of air refuelling and termed Vice Versa, demonstrates how the larger transport aircraft could be refuelled using this technique.

In the orthodox air-refuelling system the tanker flew straight and level, while the receiver manoeuvred his aircraft into position, made contact and flew in formation. This procedure was found satisfactory with bomber and fighter aircraft because they were inherently manoeuvrable, and the pilots concerned were trained to fly in formation, but even with trained pilots it was necessary for them to be in current receiver practice.

In formation flying, the following aircraft required a reserve of power in order to maintain station. In power-limited aircraft, such as the Argosy, the practical performance envelope for the combination would be improved if the Argosy flew straight and level, with a more powerful tanker formatting on it, than if the Argosy itself had to make contact and fly in formation.

For satisfactory station keeping, the formatting aircraft required 10-15% power in reserve, as compared with the lead aircraft.

A further factor was that if passengers were carried in the transport aircraft, the accelerations applied to the aircraft

while manoeuvring for contact could have a disturbing effect on them.

Additional flight safety would result if the tanker had jet engines, as the possibility of fouling propellers with the drogue in the event of a missed contact would be eliminated.

To overcome these problems, the 'vice versa' was conceived, in which the receiver flew straight and level, trailing the hose and drogue, and the tanker, equipped with a probe and pumping equipment, made the contact.

The following provisional study of the technical problems that were involved showed that it was a feasible system but would require development.

System arrangement

Illustrated in [Fig 253](#) is the distribution of the equipment required between tanker and receiver aircraft.

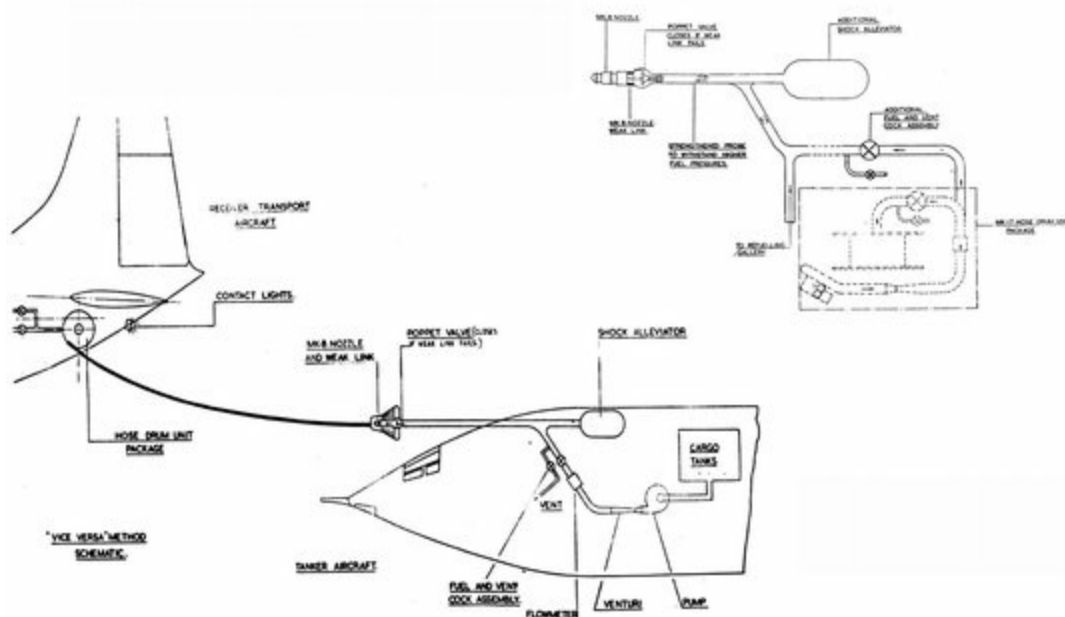


Fig. 253. Vice versa air refuelling

Receiver aircraft would be equipped with a hose-drum unit, which would be connected via a fuel and vent valve to the parent aircraft's gallery fuel system. The hose-drum unit was required to perform the following operational sequences:

1. Trail the refuelling hose.
2. Provide the necessary hose response when a tanker made a contact.
3. Rewind the refuelling hose.
4. Normal and emergency braking sequences.
5. Hose-jettison facility.
6. Contact light signalling.
7. Fuel and vent valve control.

From the above functions all of them were already provided in existing equipment, i.e. the Mk XVII package and Mk XX series of refuelling pods, which in the vice-versa system still performed their normal automatic functions without the complications of fuel pumping and control. The contact lights would be arranged in the orthodox manner, so that when a contact was made the hose would be vented and the Amber light illuminated. When a contact had been established (hose wound in 5-8 feet), the fuel valve would open, the vent valve closed, and the Green contact light illuminated to inform the tanker crew that the fuel transfer could commence

It was appreciated that the hose-drum unit represented an increased weight penalty on the receiver aircraft as compared with a probe installation. This penalty would be proportional to the rate of flow required, but was unlikely to exceed 800 lb (or 100 imperial gallons) of fuel (in the worst case a Mk XVII with the capability of transferring 500 imperial gallons per minute), and would be negligible in the case of a Mk XX pod capable of transferring 150 imperial gallons per minute.

The hose-drum unit would be installed in the transport aircraft as a removable package to reduce the tare weight

when flight refuelling was not required. Fixed fittings would comprise structure attachments, power supplies, control cables and a pressure-refuelling manifold tapping.

The tanker aircraft would be equipped with a probe, shock alleviator, fuel and vent valve flowmeter, fuel pump and cargo tanks.

The probe would be equipped with a standard Mk 8 probe nozzle and weak link, backed with a normally open poppet valve that would close in the event of a weak-link failure (loss of nozzle). In the event of an emergency breakaway, the probe would see a higher fuel surge pressure than normal in conventional probes, and would need to be stronger, with further protection provided by a shock alleviator. Running pressure in the probe would also be higher than normal, as the hose-drum unit pressure drop and, say, 5 psi (0.34 bar) for the static head difference between the two aircraft would be superimposed on the 50 psi (3.4 bar) pressure required at the receiver manifold.

The fuel and vent valve ensured that the probe was not pressurized at the moment of contact. The valves would be under the direct control of the pilot or co-pilot with a 'dead man's' handle type of application. The fuel valve would be selected to open when the Green contact light was seen from the receiver, and selected closed before disconnecting, or when a fuel transfer was completed. Automatic closure of the fuel valve could be readily provided if preselected fuel quantities of fuel were to be transferred.

The fuel pump and cargo tanks would be of orthodox arrangement.

Victor tanker vice versa

The vice versa arrangement for an existing Victor tanker is illustrated in [Fig 253](#), and it is apparent that the equipment requirements largely existed in the aircraft. The cargo tanks, fuel pumps and flowmeter were suitable for the vice versa

system, and a tapping was taken off the Mk 17 package fuel manifold to feed an additional fuel and vent valve, which was then fed to the strengthened probe, the probe still being able to be used in the receiver role.

Minor modifications to the fuel pump control system would be required in order to select a changed venturi datum level when the vice versa system was in use.

From the above it follows that with relatively small modifications the existing Victor tanker would fulfil its present role as a receiver, as a tanker for fighter and bomber aircraft, and as a vice versa tanker for heavy transport aircraft.

A summary of the above showed:

1. The vice versa system of refuelling overcame pilot difficulties likely to be experienced with heavy transport aircraft.
2. Existing Victor tanker aircraft could be adapted to the vice versa system.
3. More detailed investigation of the technical implications were suggested.

No further interest was shown in this possible technique.

CHAPTER TWENTY-FIVE

Mk 20F Refuelling Pod

In 1968 the then British Aircraft Corporation (Operating) Ltd placed an enquiry on Flight Refuelling Ltd, Ref. E/AFJ dated 7 May 1968, for an aircraft refuelling pod for the SEPECAT Jaguar aircraft. It was intended to mount the pod on a fuselage pylon mounting, the space envelope being to specification 121.SP 52/65.

The proposed pod was based on the Mk 20 series of refuelling pods, but the requirement for this equipment was to have a 250-imperial-gallon (1,125 litres) fuel-tank.

The proposed design therefore included the use of the Mk 20 power unit and hose-drum unit inclusive with the relative fairings, so that it was only necessary to design the centre-section fuel-tank, as shown in [Fig 254](#).

The fuel tank had pressure bulkheads at the forward and rear ends and was a fabricated riveted construction, sealed with PRC synthetic rubber sealant, having a capacity of 250 imperial gallons (1,125 litres), of which 231 imperial gallons (1,040 litres) was usable fuel. The fuel-tank did not require air pressurization for the transfer of fuel in the flight refuelling role; however, when the fuel was transferred from the tank to the aircraft's fuel system the normal pressurization system had to be used via the vent connection to the tank.

Mounted externally on top of the tank were the service connections, which mated with the aircraft services located on the fuselage pylon. These comprised the necessary

electrical connections, a nominal 2½-inch (63 mm) fuel inlet, air vent connection, two yaw spigots and two aircraft hook units. Also built integrally with the tank structure were the hard points required for crutching the

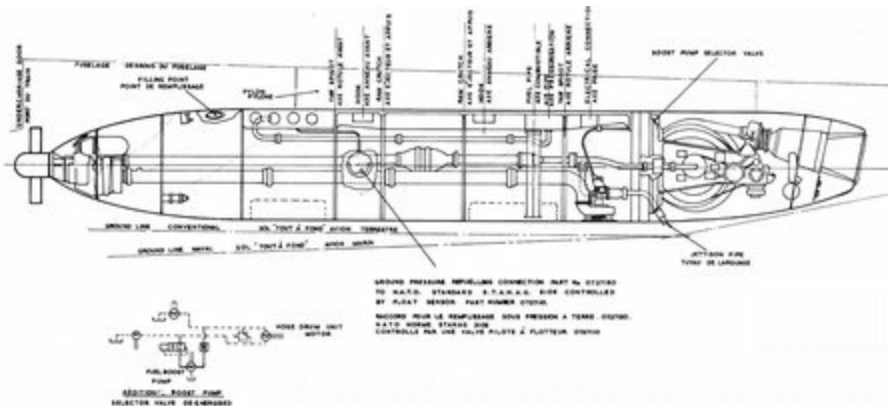


Fig. 254. Mk 20F refuelling pod for Jaguar

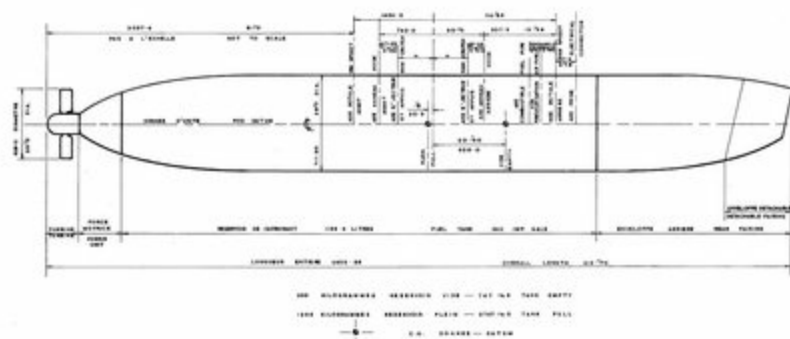


Fig. 255. Mk 20F refuelling pod dimensions, weights and CG

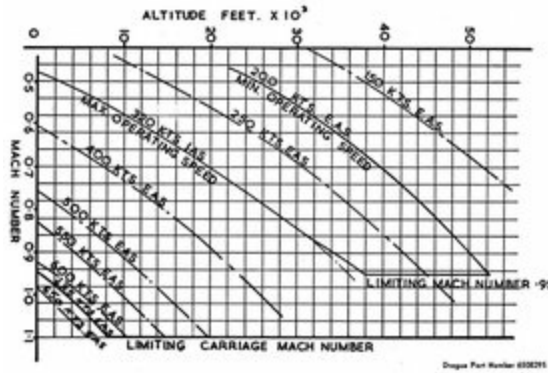


Fig. 256. Mk 20F height/speed envelope

refuelling pod to the aircraft's pylon and ram pads for the pod's ejection from the aircraft. The arrangement thus permitted the refuelling pod to function as a standard drop tank.

The overall dimensions, weights and centre-of-gravity position of the pod are shown in Fig 255. Located at the forward end of the fuel-tank was a ground filling aperture permitting the tank to be refuelled with a non-pressure-refuelling unit; alternatively the tank could be pressure refuelled by the means of a further refuelling connection located on the side of the tank in a central position, the valve within the pressure refuelling connection closing automatically when the tank was full.

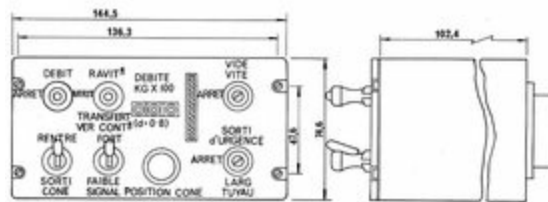


Fig. 257. Mk 20F refuelling pod control panel

The main fuel-transfer pump, although attached to the power unit, protruded through the forward tank bulkhead,

and operated within the tank. On the suction line of this fuel pump was a further pump. This pump was hydraulically driven unit, the hydraulic power being supplied from the pod's hydraulic system and incorporated to boost the fuel to the forward pump, thereby permitting the Mk 20F refuelling pod to operate at any altitude shown in [Fig 256](#), without the necessity of tank pressurization.

Also housed within the fuel tank were float-switches that signalled tank empty, tank half full, and tank full, and a jettison valve, permitting fuel jettison at 85 imperial gallons (383.40 litres) per minute, fuel pipe lines and other system equipment.

Access to the interior of the fuel-tank was gained through suitably positioned access panels, though these were required only for major servicing.

The miniaturized operator's control panel (Fig 257) was of similar construction to the existing standard Mk 20 series control panel. The design of the Mk 20F panel reduced the number of switches and indicators to the minimum required to control the functions of the refuelling pod automatically.

Services control panel

The following were provided:

1. Fuel-flow (from hose) switch (opened solenoid valve for fail-safe shut characteristic)
2. Trail and wind switch
3. RED warning light) Incorporated in AMBER ready light)
one lamp unit GREEN fuel passing light)
4. Fuel-jettison switch (solenoid valve in pod using 0.3 A current, 28 V DC)
5. Resettable fuel-quantity-gone indicator (calibrated in kilograms weight of fuel transferred)
6. Emergency trail switch/emergency hose-jettison switch)
7. Day/night dimming-switch (for pod contact lights)

8. Fuel transfer switch (pod-aircraft or aircraft-pod)

No panel illumination was provided on the panel in the form presented. However, if panel illumination was required it could be incorporated with the additional facility of day/night lighting.

Weights and dimensions of Mk 20F refuelling pod

All-up weight of pod,

full condition2,767 lb (1,257 kg) (using
fuel of 0.83 SG)

Empty weight747 lb (339 kg)

CG position relevant to centre line

Tank empty20 inches (508 mm) aft

Tank full.....0.8 inches (20.3 mm) fwd

Maximum diameter28 inches (711.2 mm)

Overall length212.7 inches (5,402.6 mm)

Maximum tank pressure in an emergency
(refuel shut-off valve

failure)45 psi (3.16 kg/cm²)

Length of refuelling hose50 feet (15.4 m)

Hose internal bore1.50 inches (38 mm)

Total capacity of fuel-tank250 imperial gallons (1,125
litres)

Usable fuel231 imp gall 1,040 litres Outside
diameter

of drogue28 inches (711.2 mm)

Operator's Control Panel (miniaturized)

Maximum width5.70 inches (144.5 mm)

Maximum height2.90 inches (74.6 mm)

Maximum depth

(not including electrical

connection)4.00 inches (102.4 mm)

Fixing centres width5.37 inches (136.3 mm)

Fixing centres height1.87 inches (47.6 mm)

Estimated weight of panel assembly3 lb (1.36 kg)

The overall operating performance of the refuelling pod was identical to the Mk 20A, Mk 20B, and Mk 20C refuelling pods. However, the equipment had been in service for nearly eight years, and to support the proposal service experience was included.

The Mk 20 series of aircraft refuelling pods had been in service with the Royal Navy since 1960. These had seen service throughout world-wide conditions on Royal Navy Buccaneers, Sea Vixens and Scimitars.

Similarly the Mk 20 series had been in service with the Royal Air Force since 1965, and had also seen service throughout world-wide conditions on the Victor and trials on the Argosy.

Approximately 150 Mk 20 series of aircraft refuelling pods had been manufactured.

Once again, this proposal had been put forward for the Jaguar but did not come to fruition.

CHAPTER TWENTY-SIX

Handley Page Victor

K2 Tanker

Refuelling operations with the Victor K1 and K1A during the 1960s and 1970s identified a requirement for a new tanker with an increase in range and a larger fuel load, together with an increase in power.

Late in 1968 it was decided to convert either B2R XM.175, which had incurred wing root damage and was in store at Radlett, or XL.614, which was at St Athans, to a K2 three-point-tanker conversion. Originally twenty-eight Victor B Mk 2s were to be converted, but finally twenty-four were converted, their tail numbers being as follows:

XH.669, XH.671, XH.672, XH.673, XH.675,
XL.158, XL.160, XL.161, XL.162, XL.163,
XL.164, XL.188, XL.189, XL.190, XL.191,
XL.192, XL.231, XL.232, XL.233, XL.511,
XL.512, XL.513, XM.715, XM.717

The installation of the in-flight-refuelling equipment was similar to that of the Victor K1 and K1A, incorporating the Mk 20B refuelling pods at the wing stations, but the Mk 17 refuelling package had to be modified. This was due to the Victor B2 having an AC electrical system to supply the power to the package's hose-drum drive motor. The package was modified to incorporate a 200 V AC driving motor, and the

complete package was designated as the Mk 17B.

The increase in fuel load was added via the under-wing tanks, as shown in the Victor K2 fuel system (Fig 258), these providing an additional 7,405 imperial gallons (33,322.5 litres).

The first Victor K2 three-point tanker delivered was XL.233, which joined 232 OCU on 7 May 1974, and No. 55 Squadron was the first to receive the new tanker on 1 July 1975. Four months later the squadron was sent to reinforce the Harrier in Belize. No. 57 Squadron received the first of its converted aircraft on 7 June 1976, but 214 Squadron remained with the Victor K1As until it was disbanded in January 1977.

The Victor K2 was cleared to dispense and receive fuel by day and night subject to certain limitations. The following aircraft were cleared to receive fuel from the Victor. The table following shows that either the Mk 20B wing unit or the fuselage Mk 17B package could be used unless it stated otherwise.

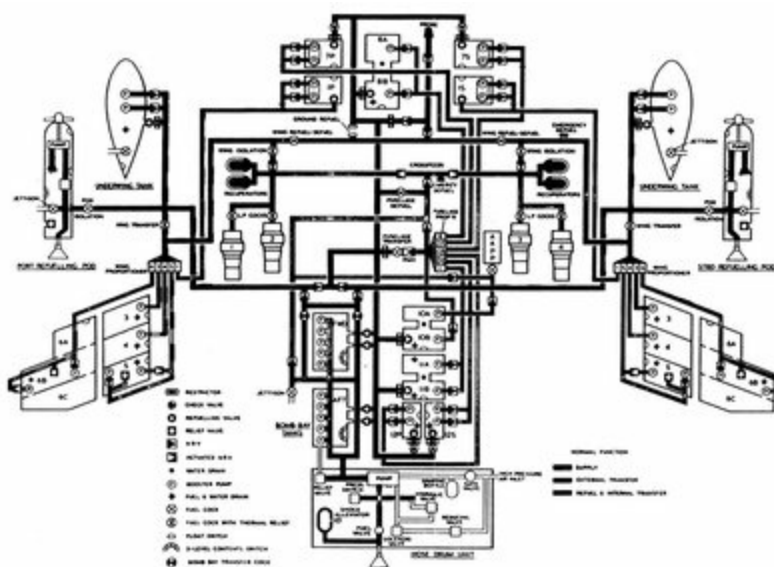


Fig. 258. Victor K2 three-point-tanker fuel system

TYPE	MARK	NOTES
BUCCANEER	ALL	
CANBERRA	B2 (WH.876)	Mk 17B only. Dry contacts for AAEE conversion and continuation of training only
HARRIER	ALL	
HERCULES	C Mk 1	Mk 17B only
JAGUAR	GR Mk 1	
LIGHTNING	ALL	
NIMROD	MR Mk 2	Mk 17B only. For essential tasks and training necessary to meet those tasks
PHANTOM	ALL	
SEA HARRIER	FRS Mk 1	
TORNADO	GR Mk 1	
TORNADO	F Mk 2	For trials purposes only
VICTOR	K Mk 2	Mk 17B only
USN		
A6 and A7		Day only

F.14

Mk 17B only. Day only

The Mk 20B and Mk 17B speed limitations are shown below.

	Mk 20 Pod	Mk 17B Package
Maximum trail and		
in-flight speed	320 kts/0.88 M	320 kts/0.88 M
Minimum trail and	Below 220,000 lb 230 kts	230 kts
in-flight speed	Above 220,000 lb 250 kts /0.85M	
Maximum in- contact	Jaguar 310 kts/0.88 M	320 kts/0.88 M
speed	Harrier 300 kts/0.88 M	
Others	290 knots /0.88 M 320 knots	
Minimum in- contact	Buccaneer)	Buccaneer)
	Jaguar)	Harrier)
	Lightning) 250 kts	Jaguar)
	Phantom)	Lightning) 250 kts
	Sea Harrier)	Phantom)

	Tornado)	Sea Harrier)
		Tornado)
		Hercules)
		Nimrod) 230 kts
		Victor Greater of cruise boundary of tanker at initial weight or cruise boundary of receiver at final weight
Maximum hose wind in speed	290 kts up to 30,000 ft, decreasing linearly to 260 kts/0.88 M at 40,000 ft 0.85 M above 40,000 ft	320 kts
Minimum hose wind in speed	Below 220,000 lb: 230 kts Above 220,000 lb: 250 kts/0.85 M	230 kts

Recommended emergency hose trail speed	200 kts up to 150,000 lb,	200 kts up to 150,000 lb,
	increasing to 230 kts at	150,000 lb, increasing
	195,000 lb	linearly to 230 kts at 195,000 lb
Recommended hosejettison speed	230 kts	230 kts

The low-temperature limitation was similar to the Victor K2 and K1A.

However, with the Falklands War occurring in 1982, the flying hours on the Victor K2 were drastically increased, as it was the main support tanker for Operation Corporate.

It operated out of Ascension Island in the South Atlantic, refuelling the majority of other aircraft operating in that area, especially with the well-known bombing of Port Stanley on the night of 30 April 1982.

Eventually the Victor K2 three-point tanker was replaced by the VC10 three-point tankers K2 and K3, and by the single-point Tristar K1. The final picture of in-flight refuelling from an F-4 Phantom in contact with the Victor K2 is shown here.

(right) Victor K2 three-point
tanker refuelling an F.4.
Phantom



(below) Victor K2 three-point
tanker on Ascension Island



CHAPTER TWENTY-SEVEN

Mk 32 Air Refuelling Pod

The origin of the Mk 32/2800 air refuelling pod was conceived through the American D704 refuelling pod having defects that were becoming a great concern for the American Navy. In 1969 it issued a specification for a mechanically operated refuelling pod in an endeavour to remove the problems of hydraulically powered equipment. Flight Refuelling Ltd decided to complete a design study for such equipment based on the performance of the Mk 20 series of air refuelling pods. The original concept for this equipment was to use the fuel within the pod to power the hose-drum unit and the transfer of fuel, and consider a mechanical method for the refuelling hose response when a receiver made contact. This description is intended to illustrate how a design concept matured into a practical production piece of equipment.

When the technical theory of the design had been sorted out, based on using the standard Mk 20 pod performance and making use of its refuelling hose and fuel transfer flow rate, the initial fueldraulic (using fuel to power the hose-drum unit) design diagram shown in [Fig 259](#) was schemed.

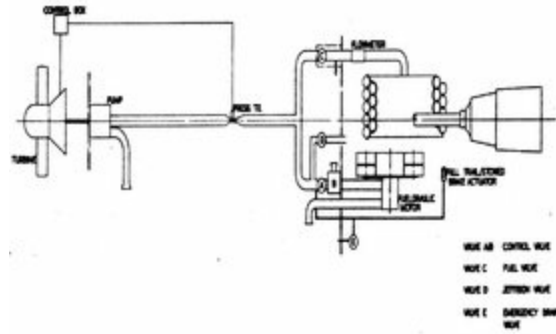


Fig 259. Mk 32 initial fueldraulic diagram

The diagram showed the initial thinking for powering the hose-drum unit via a ram air turbine driving a fuel pump supplying the power to a fueldraulic motor; thus providing the rewind power and transferring the fuel to a receiver aircraft via the use of fuel valves to control the operation.

A further general arrangement diagram was schemed showing a more practical layout, as shown in [Fig 260](#), tying in the proposed 'Tensator' spring mechanism for hose response, with the basic idea becoming a firm possibility.

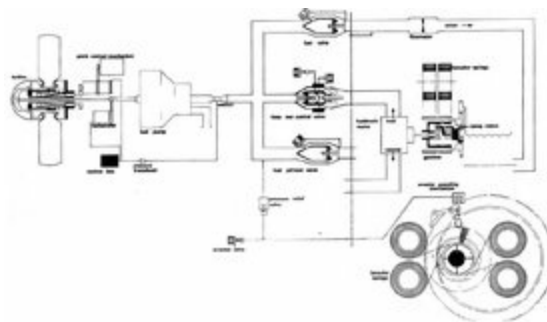


Fig. 260. Mk 32 air refuelling pod general arrangement diagram

This was the first schemed drawing of an overall system with more detail in the practical design, showing the interfacing of the fueldraulic system with the control valves and Tensator springs. However, there was still some way to go in

developing the system.

It was during this stage that a brochure entitled 'Design Study For The Investigation Of a Mechanical Spring System To Operate An Air-to-Air Hose Reel', referenced ENG/RMT/WAE/G.43/903 and dated October 1969, was produced, in which was the latest technical and design information confirming that such a piece of equipment was feasible and was of a simpler design with fewer components.

One of the intentions of the brochure was to see if the Ministry would support a development programme for future refuelling pods.

During this time further design was continuing regarding the hose-drum unit, and the required power unit comprising the ram air turbine and fuel pump. The latter two required discussions with Messrs Dowty Rotol and the Plessey Company respectively.

The result of the early design for the overall system was that it was necessary to go through each operational function and tabulate them in order to include the electrical circuits, and to look at any possible failures to enable the system to be fail-safe.

However, to complete the tabulation, initial design drawings were completed, and the early hose-drum unit design is shown in [Fig 261](#), which shows the unit with the Tensator spring unit and fuelhydraulic drive motor located on the port side, while in [Fig 262](#) the starboard side is shown with the fuel transfer piping, flow transmitter and fuel-shut-off valve. A more detailed design drawing is shown in [Fig 263](#), with the Tensator springs, the fuelhydraulic motor and the gearbox mounted in the centre of the spring unit, the motor's fuel-control valve and the early braking mechanism.

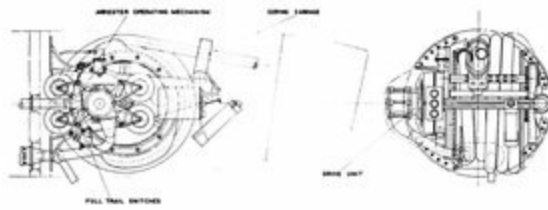


Fig. 261. Mk 32 first hose-drum unit design, port side

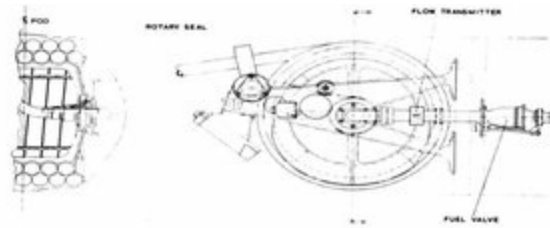


Fig. 262. Mk 32 first hose-drum unit design, starboard side

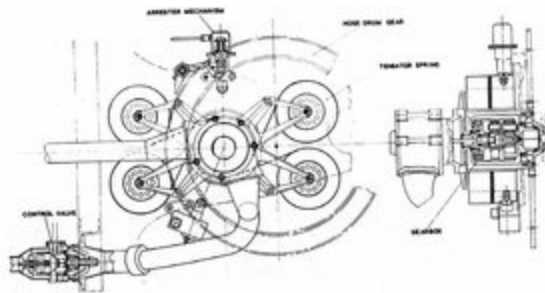


Fig. 263. Mk 32 Tensator unit, fuel hydraulic motor and gearbox

To complete the system the power unit had also to be sorted out, the initial design concept being shown in [Fig 264](#).

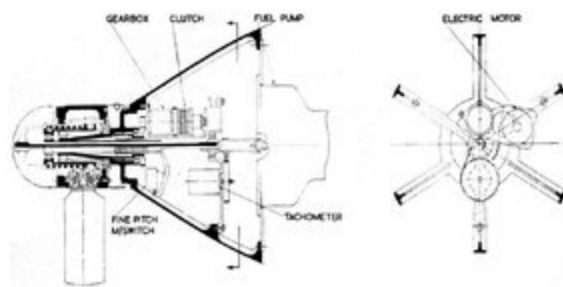


Fig. 264. Mk 32 first design of power unit

From all the design information now available the early operating sequences can now be described.

The power unit for operating the hose drum in the 'WIND' and 'TRAIL' sequences was provided by a Dowty Rotol Ltd fuelhydraulic motor driving through a two-stage-reduction, epicyclic gearbox (ratio 12:1) and a spur gear, and by a Tensator spring motor driving the spur gear via a sprag clutch during the refuelling operation. The fuelhydraulic motor was supplied with fuel via a dual-purpose control valve from the power unit's fuel pump. When 'WIND' was selected, one side of the control valve opened, permitting 90 imperial gallons (405 litres) at 50 psi (3.4 bar) pressure to power the hose drum and give a nominal wind-in speed of 3 ft/sec. When 'TRAIL' was selected, the 'Wind' side of the control valve was closed and the other opened. In this sequence the fuelhydraulic motor functioned as a pump, pulling fuel from the fuel-tank and returning it via the control valve, which in this mode functioned as a flow-control valve, thereby limiting the 'Trail' speed to 5 ft/sec. During this sequence the Tensator spring motor was powered by the hose drum transferring the springs from their bobbins to the hub of the motor, thus storing sufficient power for maintaining a constant hose tension.

Incorporated on the hose-drum unit was a brake mechanism for arresting the refuelling hose at the full trail position, when stowed and in the event of an emergency.

The mechanism consisted of two small subassemblies, of which one was the operating mechanism, and the second a spring-loaded ratchet arm that engaged a ratchet-wheel on the hose drum. The operating mechanism consisted of a fuel chamber, spring-loaded bellows, operating rod with a roller attached to it, and a ratchet release yoke, the assembly

being secured to the hose-drum port side plate.

A spring-loaded ratchet arm was also attached to the side adjacent to the operating mechanism by a torsion spring and shaft. With the two assemblies in situ the ratchet release yoke was in such a position that it controlled the actuation of the ratchet arm via the operating mechanism. The fuel chamber of the mechanism was connected to the fuel line for powering the hose drum via a small pipe that was teed into a solenoid valve connected to the fuel-tank.

The operation of the brake mechanism was such that with the hose in the 'Stowed' position and the master switch 'OFF', the brake solenoid valve was de-energized, permitting evacuation of fuel pressure and thereby allowing the spring-loaded bellows and operating rod to actuate in a vertical direction, and the spring-loaded ratchet arm to rotate and engage with the hose-drum ratchet-wheel. With the master switch selected to 'ON' the brake solenoid was energized to 'CLOSE', allowing a nominal 50 psi (3.4 bar) fuel pressure to be applied to the top of the spring-loaded bellows operating the rod of the operating mechanism. This pressure overcame the spring load, permitting actuation of the bellows and operating rod in a downwards direction, operating the ratchet release yoke to engage the hose-drum ratchet-wheel. (Note that during this sequence the hose-drum control valve was in the 'Wind' selection, which released the load applied to the brake prior to the ratchet arm becoming disengaged from the hose drum's ratchet wheel.

To brake the refuelling hose at the 'Full Trail' position, it was first necessary to reduce the trailing speed of the hose prior to braking, to prevent excessive loading of the mechanism. This was achieved by a switch unit operated by the Tensator spring motor during the transfer of the springs from their bobbins, the switch being actuated at approximately 5 feet from the 'Full Trail'. This then de-energized the solenoid on the flow-control side of the hose drum's control valve, thus decelerating the hose trailing

speed. At one foot from the full trail position the brake-operating mechanism was actuated in a similar manner, in that the roller attached to the bellows and operating rod mated with the Tensator springs that were being transferred, and was actuated in a vertical direction, releasing the yoke and permitting the ratchet arm to rotate and with a snap action engage with the hose drum's ratchet wheel.

In the event of an electrical failure the brake mechanism was so designed as to prevent further rotation of the hose drum in the 'Trail' sequence. Operation of the mechanism was that with a failure of this nature, the solenoids controlling the flow-control side of the hose-drum control valve, and the brake mechanism, were selected closed and open respectively. With these selections the braking of the hose drum was similar to that of 'Full Trail'.

The power unit ram air turbine provided the same 30 h.p. at 7,750 rpm as that employed on the Mk 20 air refuelling pod. However, the blade pitch control, which was of a simple design, was achieved via a pressure transmitter sensing the fuel pressure at the throat of a venturi within the fuel transfer line, and a tachometer drive through the fuel-pump drive shaft. Each of these transmitted an electrical signal to an electronic black box; these signals were processed within the box to provide an integrated signal to a magnetic powder clutch located in the turbine's blade-pitch drive mechanism, whereupon the tachometer signal controlled the rpm of the turbine to 7,750 rpm, or the venturi signal controlled the rpm to give a constant 50 psi at the venturi throat. In the event that a receiver aircraft was capable of accepting a fuel transfer at a high flow rate and low pressure, the tachometer signal inhibited the venturi signal and maintained the 7,750 rpm.

Within the black box was a comparator that accepted the signals transmitted from the venturi and tachometer, comparing the venturi signal with a pressure datum of 50

psi, the output from the black box being proportional to the error signal between the venturi input signal and the set datum. Similarly the tachometer signal was matched against an rpm datum. Hence, the output signal from the black box being proportional, the voltage applied to the clutch was variable, and this therefore controlled the clutch engagement by varying the torque output. When there was zero fuel pressure at the venturi throat, maximum torque was available at the clutch; similarly, when 50 psi fuel pressure was attained at the venturi throat, the signal was such that it maintained the required holding torque, or if the fuel pressure rose above 50 psi the signal was reduced, permitting the clutch to slip. If, however, 50 psi fuel was not achieved at the venturi throat, the tachometer signal ensured that sufficient holding torque was available to achieve 7,750 rpm at the turbine, and then to maintain it.

The turbine blade-pitch drive mechanism was a continuously rated electric drive unit, the drive being transmitted through a reduction gearbox (ratio 3:1) to the magnetic clutch and a reduction gearbox (ratio 20:1), to which was secured a spur gear. The spur gear of the drive unit meshed with a gearwheel secured to the external surface of a recirculating ball-screw, which when driven in either direction operated a push-pull shaft. At the forward end of this shaft a journal bearing was mounted to it that located an operating sleeve annulus that engaged with the operating pins of the turbine blades. Located between the front hub housing of the turbine and the operating sleeve was a compression spring that opposed the action of the motor drive unit. The operation of the pitch control was such that when the master switch on the control panel was in the 'OFF' position no electrical power was available, and the turbine blades were powered by the compression spring to the feathered position.

With the master switch selected to the 'ON' position, with zero fuel pressure at the throat of the venturi, the motor and

clutch (the clutch giving maximum torque) drove the recirculating ball-screw, operating the push-pull shaft, which overcame the compression spring and powered the turbine blades' 'Fine' pitch. The motor continued to power the blades until 50 psi fuel pressure was attained at the throat of the venturi, when the electronic black box reduced its output signal and a reduction of through-torque was achieved, but maintained sufficient through-torque to hold the turbine blades at the correct 'Fine'-pitch position. Should the fuel pressure at the throat of the venturi exceed the 50 psi datum pressure, the output from the electronic black box was reduced permitting the clutch to slip and allowing the turbine blades to be powered by the compression spring in a feathering direction, until such time that the 50 psi pressure was restored at the venturi throat. Should the pressure at the venturi throat not attain the 50 psi datum pressure, the tachometer signal inhibited the venturi signal, allowing the required through-torque at the clutch and permitting the turbine to achieve a constant 7,750 rpm.

With the in-depth design study on the new method of powering an air refuelling pod completed, and such a method having been proved practical, the Ministry was not interested in assisting in any development. The reasoning behind this decision was that the existing Mk 20 air refuelling pod was providing a good refuelling service with the fuel transfer flow rate identical to the new proposal, i.e. 150 imperial gallons per minute, and in particular future receiver aircraft were likely to be capable of accepting higher rates of fuel flow, and therefore less time in contact.

To achieve a higher rate of fuel flow it was necessary for a more powerful ram air turbine and a higher-performance fuel pump to be designed. This meant that further discussions would be necessary with Dowty Rotol Ltd for the ram air turbine, and the Plessey Company for the fuel pump.

Peter McGregor and I visited both companies to discuss the possibility of increasing the fuel-flow rate. Prior to any

discussions it was suggested to provide a fuel transfer flow rate of 350 imperial gallons (1,575 litres) per minute, which would require a 45 h.p. turbine, a larger bore of refuelling hose and a new fuel pump.

The meeting at Dowty Rotol Ltd with Mr P. Morris eventually proved to be very successful. The existing RAT/10 turbine used on the Mk 20 air refuelling pod could possibly be modified by using the existing blade-pitch mechanism, but changing the internal method of blade-pitch change from hydraulically operated to a mechanical operation.

Likewise with the fuel pump the meeting with the Plessey Company at Titchfield, where Peter McGregor and I met Mr J. Thompson to discuss a fuel pump with a higher rate of flow. The end result was that a fuel-lubricated fuel pump could meet the requirement, and was recommended, particularly as the company's knowledge of fuel pumps was well known, especially when the Mk 17B air refuelling package and the Mk 20 refuelling-pod fuel pumps were now its responsibility.

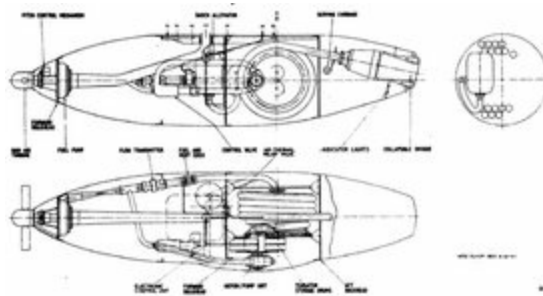
In the meantime it had been decided that the major unknown feature of the proposed new pod was in fact the Tensator spring motor and its response characteristics. Thus the motor was the only remaining unknown feature initially, as the turbine and fuel pump were coming to fruition; the fuel-transfer system and operation of the hose-drum unit were a well-known feature after the years of experience in these fields. Therefore it was concluded that it was essential to develop the spring motor through the company's research and design budget.

A test rig for the spring motor was built at Tarrant Rushton, together with a mock-up fuel system, incorporating a Dowty Fuel Systems Ltd fuel proportioner to act as a fuelhydraulic motor. The results from the testing showed that the motor did in fact provide virtually a constant-response load over the necessary range, and there appeared to be no limit to the speed of response; in other words the overtaking

airspeed of the receiver aircraft when making a contact could be increased from the existing 5 knots to something higher, which was to be proved during test flying of the pod.

With a large volume of technical and practical information now having been gained, a redesign of the proposed pod was completed in 1976, which made it even more feasible.

The revised overall design, shown in [Fig 265](#), was now designated as the Mk 32/2800, the latter four figures giving the weight of fuel transfer in pounds, i.e. 350 imperial gallons (1,575 litres) per minute. As can be seen, the complete system was now much simplified, and with very few major components, and no fuel-tank, the reliability would be increased.



[Fig. 265](#). Revised Mk 32 refuelling pod, 1976

The revised design, having no fuel-tank, now incorporated a closed-loop fuel system for both the 'Trail' and 'Wind' sequences, as shown in the overall system in [Fig 266](#).

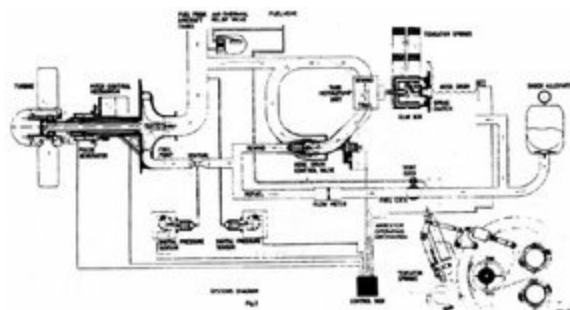


Fig. 266. Revised Mk 32 refuelling pod system, 1976

From the revised system diagram it can be seen that there was a large amount of design work carried out to make it a workable system. Dowty Rotol Ltd and the Plessey Company had completed their proposed designs, the interfaces of which were agreed with Flight Refuelling Ltd. The hose-drum brake mechanism and control valve had been redesigned, and the introduction of two pressure sensors had been incorporated.

The power unit now included the redesigned turbine and fuel pump, as shown in [Fig 267](#).

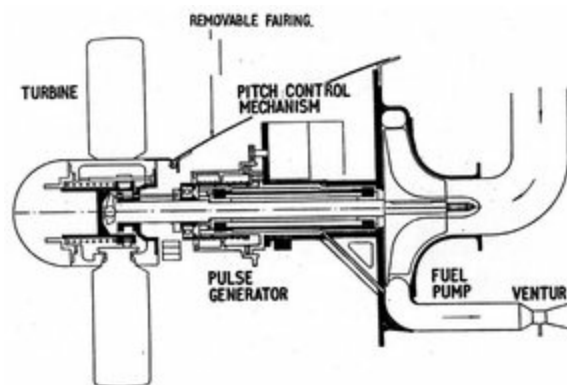
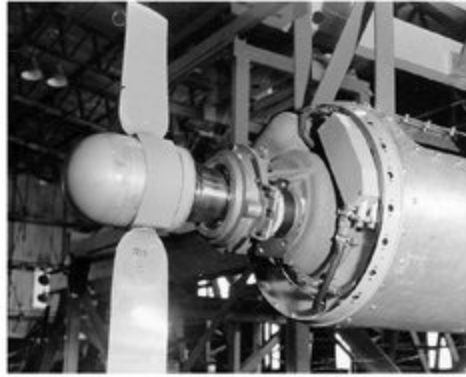


Fig. 267. Mk 32 redesigned power unit

The redesigned Dowty Rotol ram air turbine could now produce the 45 h.p. at 7,750 rpm, and the diameter of the two blades was increased from the 20 inches of the RAT/10 to 22½ inches. It was attached to the fuel pump by a simple flange, as there were no main bearings within the turbine, these now being located within the fuel pump.



Mk 32 refuelling pod turbine and fuel pump

Within the hub of the turbine were mounted the two turbine blades located on bearings beneath which were the blade-pitch operating pins. These were located within an annulus on a sleeve assembly, which in turn abutted the blade-feathering spring, the latter being incorporated within the turbine's hub. The sleeve assembly was also located on two guide pins to ensure concentricity with the fuel pump's drive shaft when operated. Secured internally of the sleeve assembly was the blade-pitch operating pad, which in turn was operated by the two push-rods within the fuel-pump assembly. The rods were now operated via a stepper motor mounted on the fuel pump, the motor being able to operate as a motor driving the blades towards the 'Fine' pitch position or hold the blades at a given position, and freewheel with electrical power 'OFF', permitting the blades to move to the feathered position rapidly via the operation of the turbine's compression spring.

The fuel pump was now a fuel-lubricated Plessey Type 7312, providing 350 imperial gallons (1,575 litres) per minute fuel outlet flow, with a pressure rise of 130 psi.

The assembly comprised the main volute body casting, which enclosed the pump's impeller mounted on the main drive shaft. Within the casting was the main-bearing housing in which were two fuel-lubricated carbon bearings, which

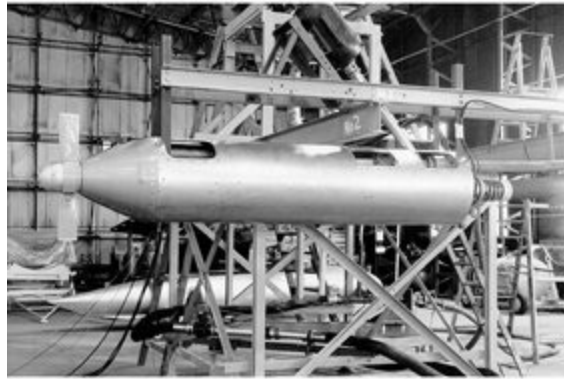
replaced the ram air turbine's main bearings. Attached to the bearing housing via a thrust bearing was a ball-screw and housing assembly, on one end of which was a machined gear wheel, and within the housing was the ball-screw located on a matched bearing assembly. Forward of the ball-screw was the turbine mounting flange incorporating two push-rods to operate the blade-pitch mechanism within the turbine hub. Mounted on the volute casting via a mounting plate was a stepper motor, the drive shaft of which incorporated a gear that meshed with the gear on the ball-screw. Thus when power was applied to the stepper motor the ball-screw housing would rotate, driving the ball-screw and in turn moving the push-rods forward against the turbine compression spring powering the blades from the feathered position to the required blade-pitch angle. When power was removed from the stepper motor the turbine blades automatically returned to the feathered position under the load from the compression spring.

Also mounted on the front face of the volute casting were two electronic speed sensors; one of which controlled the turbine's normal maximum operating speed, the second sensing an overspeed of 9,200 rpm, which automatically removed the power supply to the stepper motor, thereby permitting the blades to return to the feathered position.

Normally when fuel was being transferred to a receiver, a maximum fuel flow would only occur if the receiver was low on fuel and more fuel-tanks were available for refuelling. During the refuelling operation the aircraft's fuel-tanks would automatically be shut off, whereby the required fuel flow would be reduced. This indication was derived from the venturi within the refuelling pod's transfer system via a pressure sensor signalling that a reduced turbine blade-pitch angle was required, reducing the flow, the stepper motor driving the blades to the required angle.

To enable early testing of the turbine and fuel pump a complete mock-up of the fuel-transfer system only of the pod

was designed and built, enclosed within a dummy pod, together with a header fuel-tank to provide the necessary fuel pump inlet pressure, as shown below.



Mk 32 mock-up fuel-transfer-system rig

This rig was then transported to the blower tunnel at A&AEE Boscombe Down to prove the turbine and fuel pump performance and control system.

The tunnel had various sizes of nozzles that could simulate airspeeds up to 300 mph, and the mock-up system is shown positioned for testing below.



Mk 32 mock-up fuel system in blower tunnel

The testing of the system was a joint development for Messrs Dowty Rotol Ltd, the Plessey Company and Flight Refuelling

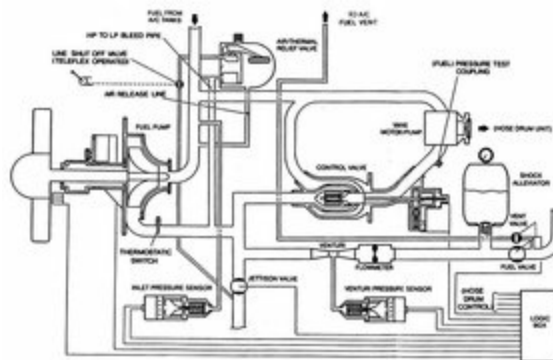
Ltd. It was satisfactorily completed, and provided sufficient confidence in the new system.

A large amount of development investigation had been carried out to provide the confidence required of the new system and its feasibility. Included now in the investigation were the fueldraulic motor, of which a new concept was designed by Flight Refuelling Ltd, a new hose-drum control valve and a revised and improved braking system. These are described later in the final design of the refuelling pod.

In August of 1979 the Ministry of Defence Procurement Executive issued a specification for the development of the Mk 32/2800 in-flight-refuelling pod for the Vickers VC10 tanker aircraft, the specification being DTD/RDI 3970, dated 7 August 1979.

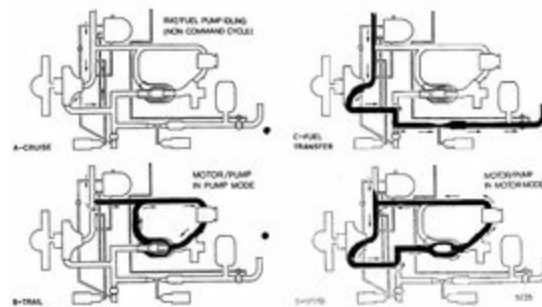
After ten years of continuous unsupported development it was now possible to complete the prototype design of a fueldraulically powered refuelling pod, and as will be seen the components required to operate an air refuelling pod were much reduced.

Initially the overall system was drawn up diagrammatically with all of the latest and some of the already proved components, as shown in [Fig 268](#).



[Fig 268](#). Mk 32 air refuelling pod prototype systems diagram

As can be seen from the prototype systems diagram, the pod no longer had a fuel-tank, and all fuel was taken from the parent aircraft for all the operations. As previously mentioned, the 'Trail' and 'Wind' sequences were through a closed-loop system, as shown in the following [Fig 269](#).



[Fig. 269](#). Mk 32 closed-loop operating system

The power unit (turbine and fuel pump) had been proved, and the other important features of the system were the fuelhydraulic motor and the hose-drum-unit control valve. In the Tensator spring motor development the motor used was a Dowty fuel proportioner, which did not prove to be very satisfactory, and so a new design by Flight Refuelling Ltd was investigated. This was based on an eccentric main drive centre to the bore of a not circular volute, which had a standard radius 180 degrees apart, joined by a sine wave curve. The centre-drive hub had three carbon-fibre blades that matched the diameter at any given point round the volute bore. Initially one of the blades failed due to the fibres being incorrectly positioned (shown below), but this was quickly overcome. The blades ran on a chromium surface around the bore and was highly satisfactory. The motor was now divorced from the hub of the Tensator spring motor and drove the hose drum through an epicyclic gearbox secured to its driving shaft, the ratio of which was 4:1, as shown in [Fig 270](#).

Mk 32 fuel hydraulic motor showing damaged blade

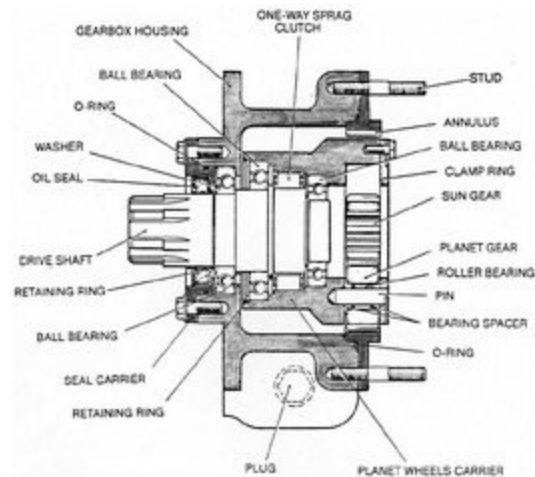
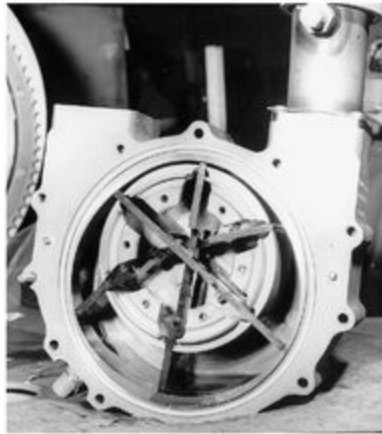


Fig. 270. Mk 32 epicyclic gearbox

The epicyclic gears, together with a sprag clutch, were enclosed within a cast body, being secured directly to the fuel hydraulic motor and to a hose-drum drive unit, the output shaft of which had a chain sprocket to connect with the hose drum, and also incorporated a hose-drum speed sensor, as shown in Fig 271.

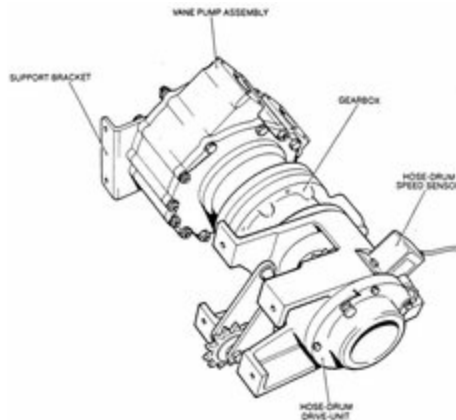


Fig. 271. Mk 32 hose-drum drive unit

The drive unit comprised a light-alloy housing with four mounting feet, a drive shaft, a chain sprocket, a speed-sensor disc and electronic sensing unit, and a chain tensioner.

The speed-sensor disc was circular, having a ring of twenty-five holes skirting its outer edge. The disc passed between two lobes on the electronic speed sensor, which was mounted on the exterior of the drive-unit housing. The sensor incorporated light-emitting diodes, so that when the disc was rotated an electronic pulse was generated, which varied with the speed of the refuelling hose's either 'Trailing' or 'Winding' sequences. The signal derived from the pulses was fed via the electronic control circuits to the stepper motor on the hose-drum control valve, thus opening or closing the 'Trail' and 'Wind' ports of the valve, thereby controlling the speed of the refuelling hose.

The hose-drum drive unit provided the mounting for the complete assembly and was secured to the rear bulkhead of the pod's structure.

During the 'Trailing' sequence the fueldraulic motor acted as a pump via the rotation of the hose drum, through the refuelling hose being pulled off the hose drum by the drag of the drogue. When a receiver aircraft made a contact and

body. Attached to the forward end were two internal fuel flow chambers, one for the 'Trail' sequence, the other for 'Wind'. The former was connected to the fuel-draulic-motor return pipe, and the latter to the bifurcation from the fuel-draulic motor outlet.

In the centre of the assembly was the mounting for the valve's sleeve assembly, which comprised a shaft having the sleeve secured to it, at its aft end a gearwheel that meshed with the stepper motor, and a ball-screw and nut, the latter being within a small housing. At the forward end and in the centre of the valve were two spring housings that enclosed a return spring, and these abutted to shoulders on the sleeve shaft. Thus when the stepper motor was energized a spring load was imparted in either direction, and when de-energized the spring load automatically returned the sleeve to the central position, thereby closing the 'Trail' and 'Wind' ports.

The operation of the valve was selected at the pod's control panel. The stepper motor was energized to drive the sleeve forward, opening the trail port, and during the trailing operation its position was determined via the speed sensor on the hose-drum drive unit, thereby varying the open position to maintain a trailing speed of 5 feet/sec. Similarly, in the 'Wind' sequence, the sleeve was moved in the opposite direction, opening the wind port, the speed of the hose being controlled in a similar manner via the speed sensor.

To complete the overall fuel-control system it is now necessary to describe it.

The fuel inlet pipe connected from the tanker aircraft's interface to the Plessey fuel pump on the power unit had connected to it an air/thermal relief valve and an inlet pressure sensor, as shown in [Fig 273](#). The exhaust port of the valve was connected to a fuel-jettison pipe downstream of its shut-off valve, the basis of the relief valve being similar

to that used on the air refuelling packages. The assembly was a float chamber, and so if air was present within the system, the float being in the lower position within the chamber, it would open the chamber to atmosphere and allow the air to escape, at the same time inhibiting the power unit from functioning until fuel under pressure was present.

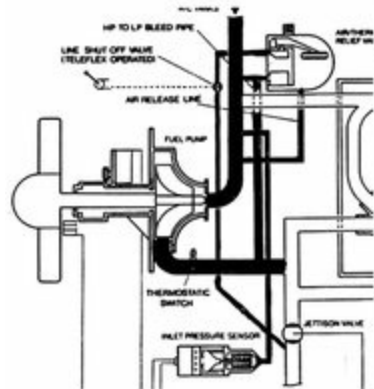


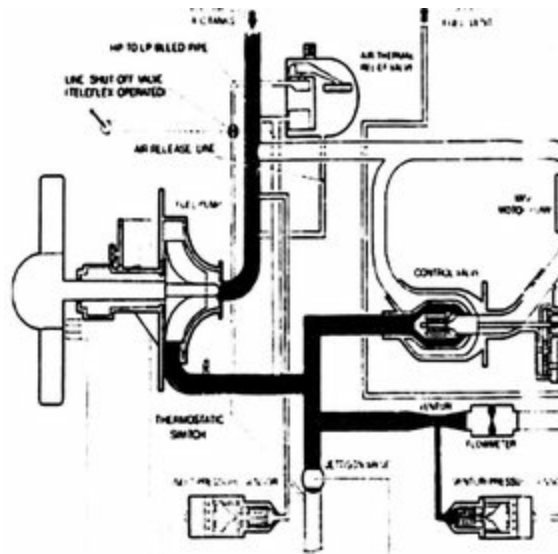
Fig. 273. Mk 32 air/thermal relief system

The inlet pressure sensor provided electronically information on the inlet pressure to ensure that the fuel pump did not cavitate through lack of fuel pressure, and signalled the ram air turbine to either increase its speed via the blade-pitch angle, or return the blades to feather if insufficient fuel pressure was available.

The fuel outlet from the pump was bifurcated, one pipe being connected to the hose-drum control valve, the other to a venturi; downstream of the venturi a further pipe was tapped in, providing a fuel-jettison facility that incorporated a fuel shut-off valve.

Connected to the throat of the venturi was a further pressure sensor, which sensed the fuel pressure at the reception coupling. This also provided electronically information on the fuel pressure during a fuel transfer that was to be maintained at 50 psi (3.4 bar); any variation in

pressure was signalled through the control system to either increase or decrease the fuel pump's speed via the ram air turbine's blade-pitch angle, thus maintaining a constant fuel pressure, as shown in [Fig 274](#).



[Fig. 274](#). Mk 32 fuel pump outlet system

Downstream of the venturi a fuel flow transmitter, a fuel surge alleviator and a fuel/vent shut-off valve were incorporated in the fuel pipe prior to being connected to the hose-drum unit and thence to the refuelling hose and reception coupling. The hose-drum unit assembly was mounted between two machined side plates, which were secured to the rear two bulkheads of the pod's structure, as shown in [Fig 275](#).

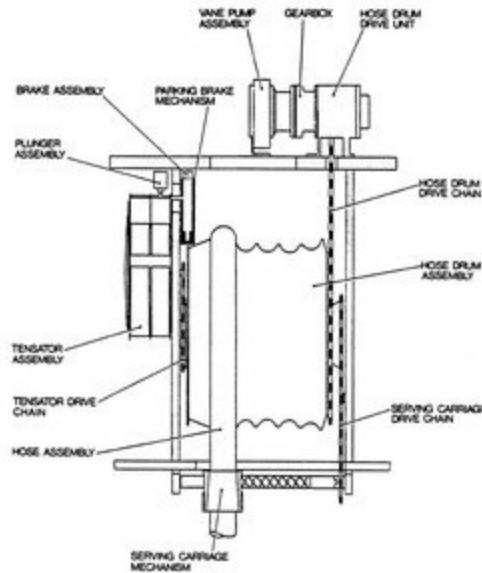


Fig. 275. Mk 32 hose-drum unit configuration

The hose drum was a convoluted casting, the convolutions layering the refuelling hose correctly when rewound. It was driven via a chain drive from the hose-drum drive unit powered by the fuelhydraulic motor, as shown in Fig 276.

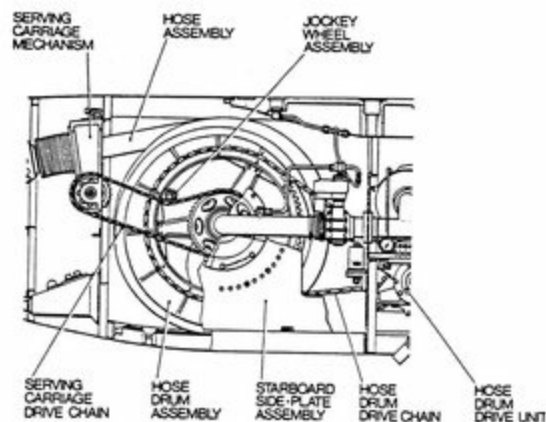


Fig. 276. Mk 32 hose-drum unit, starboard side

The hose-drum unit assembly included a refuelling-hose serving carriage to assist in layering of the hose. This was

also chain driven from a drive sprocket on the starboard side of the drum. Attached to the starboard machined side plate was the main fuel-transfer pipe, together with the fuel and vent valve. The pipe was connected to the drum via a Flexibox rotating seal similar to those on other equipment.

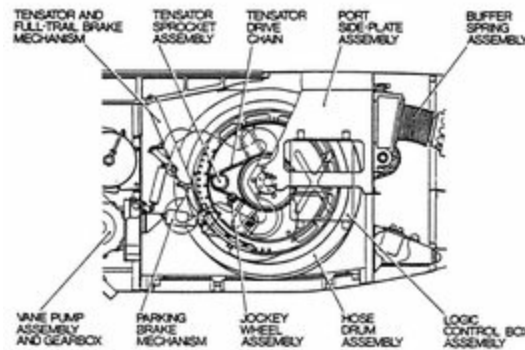
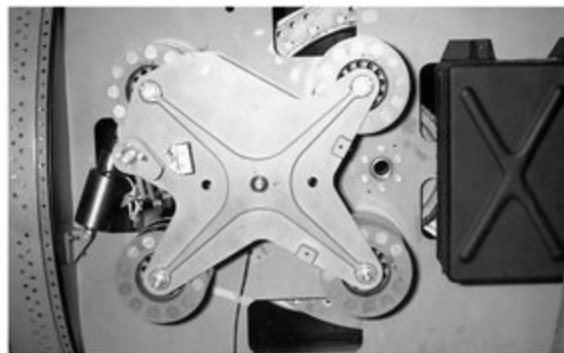


Fig. 277. Mk 32 hose-drum unit, port side

Similarly chain driven from the drum on the port side was the Tensator spring motor and braking mechanism, all of which was completely redesigned from the earlier proposal, and adjacent to the spring motor was the electronic logic box that controlled the electronic circuits, these being shown in [Fig 277](#).



Mk 32 air refuelling pod Tensator spring motor

The Tensator spring motor comprised a total of eight springs located in pairs on bobbins, all being fixed to the hub of the unit, and thus capable of being transferred to the hub via the hose-drum drive chain during the trailing sequence, thereby providing the stored power for the hose response when a receiver made contact. However, the springs were not transferred from their bobbins over the full trailing sequence due to their extended length being shorter than the 50-foot trailing length of the refuelling hose. To overcome the length difference in the centre of the hub connected to the motor's drive shaft was a lead screw and an intermediate drive shaft, the latter housing a lead screw nut, as shown in [Fig 278](#). The lead screw nut was set to allow 15 feet of hose to trail without driving the bobbins; when this length had been trailed, the lead screw nut engaged with the drive shaft, thus transmitting the drive through the intermediate drive shaft and allowing the springs to transfer from their bobbins to the hub, thereby providing 35 feet of hose response length from the full trail position.

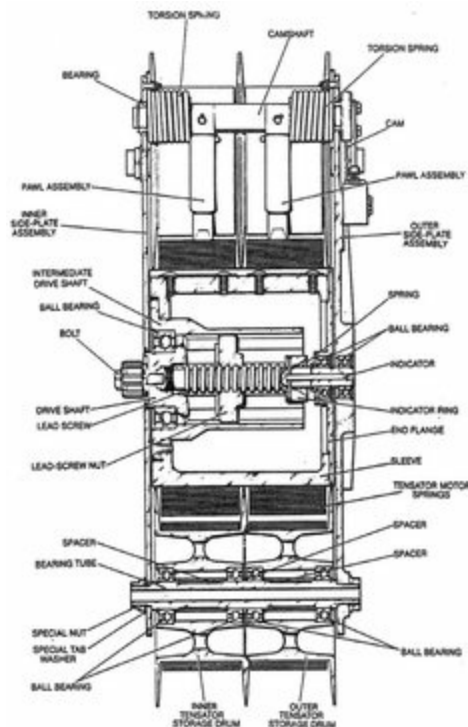


Fig. 278. Section through Tensator spring motor

Later, because of the high loading and brittleness of the springs, it was considered that it was essential to provide a guard over the Tensator assembly. Also, a special lifting sling was introduced for use when the assembly was removed from the pod. The guard was made of stainless-steel mesh and sheet metal, having access holes to enable the necessary adjustments to be made, and securing bolt removal, as shown below.

Mk 32 Tensator motor guard and lifting sling



The hose-drum full-trail brake was operated automatically via the Tensator spring motor being sensed by twin adjustable roller arms running on the top surface of the Tensator springs, their movement being caused by the varying spring layers on the hub diameter, so that at the full-trail position the rollers were on the minimum spring layer diameter, and at the maximum when the stowed position was reached, as shown in [Fig 279](#).

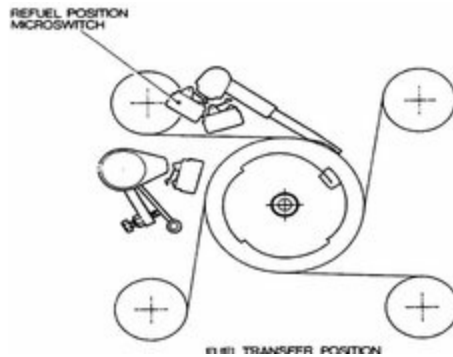


Fig. 279. Tensator spring motor at full trail, showing roller arms engaged with springs

The full-trail braking mechanism was operated via a lay shaft connected to the twin roller arms, and thence through a linkage to the shock-absorbed brake pawl, as shown in [Fig 280](#).

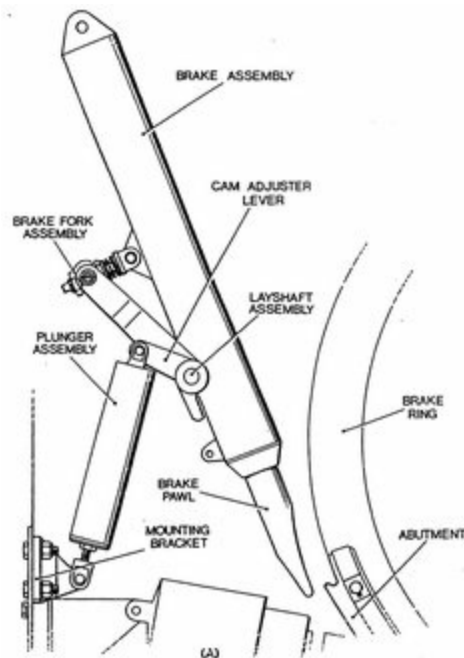


Fig. 280. Hose-drum full-trail brake mechanism

The brake pawl engaged a combined abutment and ratchet segment attached to the hose-drum brake ring, the pawl

engaging the abutment at the full-trail position, the ratchet portion being used for a parking brake when the hose was fully stowed.

The pawl was shock absorbed by being enclosed within a cylinder containing a series of conical belville washers stacked alternately, thus providing a spring absorption under load. The cylinder was attached to the aft main bulkhead of the pod structure by a pivot. Attached to the cylinder was a brake-fork assembly lightly spring loaded, which in turn was located on the brake lay shaft; adjacent to which was a cam adjuster lever that was also connected to a plunger assembly, the latter being a spring-loaded cylindrical assembly and also attached to the aft bulkhead.

The operation of the brake mechanism was such that the plunger assembly held via its spring load the brake pawl out of engagement; however, as the Tensator springs were transferred from their bobbins to the hub of the motor during the trailing sequence, the twin roller arms also secured to the lay shaft overcame the spring load in the plunger assembly, driving the brake pawl onto a brake ring attached to the hose drum, and finally engaging with the brake abutment, thereby stopping any further rotation of the hose drum.

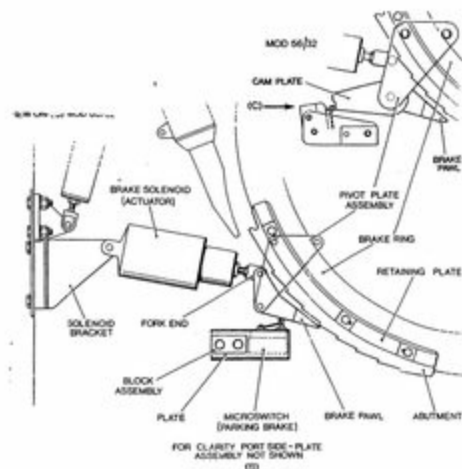
To provide an indication that the brake had been applied to the hose drum, on the end of the lay shaft was secured a cam that operated a microswitch, which when made illuminated a brake 'ON' light on the control panel.

To ensure that the Tensator spring did not become separated from the spring motor's hub when the hose was fully wound in, and also to prevent any further rotation, two spring-loaded pawls were located at the top of the Tensator spring-motor assembly, the lay shaft of which had a cam attached at one end. The cam operated two microswitches, the full-trail hose-jettison facility and the refuel position to open or close the fuel and vent valve in the fuel-transfer

system. The pawls were held in a downwards direction by a torsion spring attached to them, ensuring that they ran on the top surface of the Tensator springs during both the trail and wind sequences. When the refuelling hose was fully wound in, the two pawls that were also spring loaded in their assembly engaged with an abutment on the Tensator motor's hub, thereby preventing any further rotation of the hose drum and allowing the parking brake to be applied.

The hose-drum parking brake was to prevent any further rotation of the hose drum once the hose was in the stowed position, thus preventing it trailing. The parking brake is shown in [Fig 281](#).

Fig. 281. Mk 32 hose-drum parking brake



The brake operation was via a solenoid, which when de-energized held the brake in the 'OFF' position via its internal spring, and when energized allowed its brake pawl to engage with the ratchet teeth on the brake abutment segment. The rear end of the solenoid was attached to the aft structural bulkhead, the forward to a brake pawl located between a pivot-plate assembly. The brake pawl originally operated directly onto a parking-brake microswitch, thus providing an indication that the brake had been applied;

however, a modification was incorporated later, introducing a cam for the operation, and an elapsed-time-indicator microswitch. The operating sequence for the parking brake was as follows. Initially, when 'Wind' was selected, the hose drum rotated in the wind direction, allowing the de-energized solenoid to let the brake pawl disengage, and was now held in the 'OFF' position until the hose was rewound. When the refuelling hose reached the pre-stow position on rewinding, the magnetic shunt on the serving carriage energized the parking brake solenoid, thus driving the pawl to engage with the brake ring and then the ratchet teeth, allowing it to ratchet over a short distance. When the hose was fully stowed and the master switch was selected to 'OFF', the hose drum was locked stationary due to the reception-coupling buffer spring pulling the drum in the trail direction, so that the parking-brake pawl was kept engaged with the ratchet teeth.

The hose drum was a magnesium alloy casting, the barrel of which had cast convolutions to provide correct layering of the hose when it was wound in. Internally was the fuel transfer pipe, which was connected to a solenoid-operated hose-jettison mechanism, as shown in [Fig 282](#), which comprised a solenoid-released jack connected to a ball-catch that secured the hose to the drum; a foul bar was incorporated to prevent the rapid rewind of the drum due to the action of the Tensator motor, which when operated engaged with the starboard side plate. The slip rings to supply the electrical power to the jettison solenoid were located adjacent to the port drum bearing. A hose-motion switch, actuated via a flat on the serving-gear shaft, flashed a control-panel light when the hose was in motion.

The refuelling-hose serving carriage was located on the rearmost frame of the pod's structure, (bottom photo), being driven via the hose drum. The pre-stow

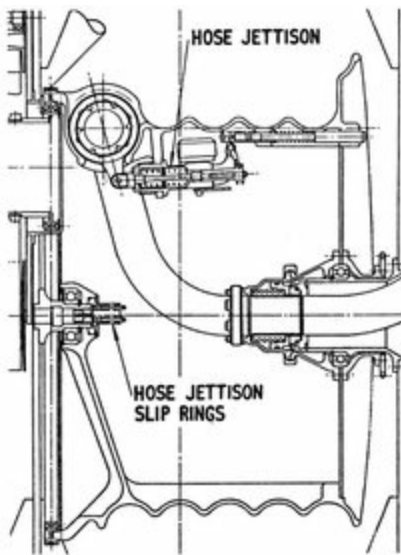
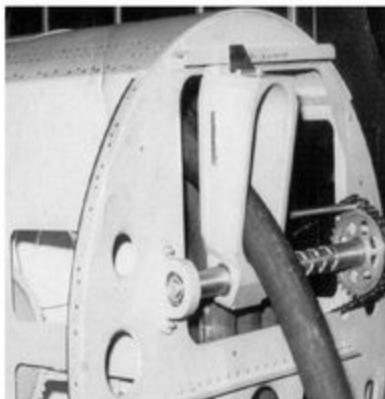


Fig. 282. Mk 32 hose drum

position of the hose was signalled via a blade passing the magnetic shunt. The Archimedean shaft that drove the serving carriage at the bottom was attached to the side frames of the hose-drum unit, and at the top the carriage ran on rollers through a channel also attached to the side frames.

The refuelling hose was now a 2-inch bore x 55 feet in length (50.8 mm x 16.9 m), constructed in a similar manner to the earlier hoses. Connected to the end of the refuelling hose was a Mk 8 reception coupling, and a collapsible drogue designed for use with the new hose.



Mk 32 hose serving carriage

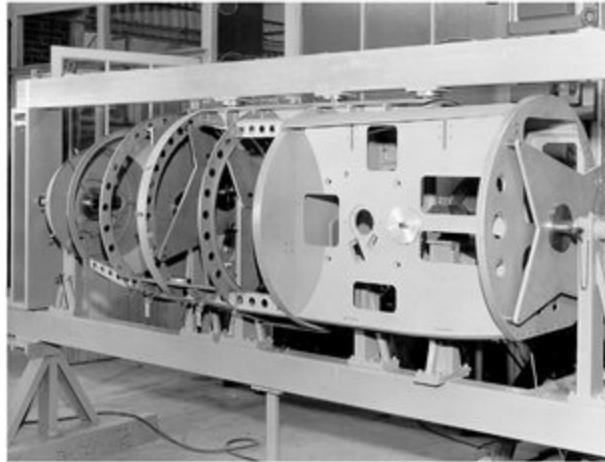
The pod's structure did not comprise a fuel-tank, as all the fuel for its operation was taken from the parent aircraft's fuel system. However, it was of a monocoque fabricated and riveted construction, as shown below, having a machined bulkhead to accept the ram air turbine and fuel pump at its forward end, and a further, larger machined bulkhead forward of the hose-drum unit bay.



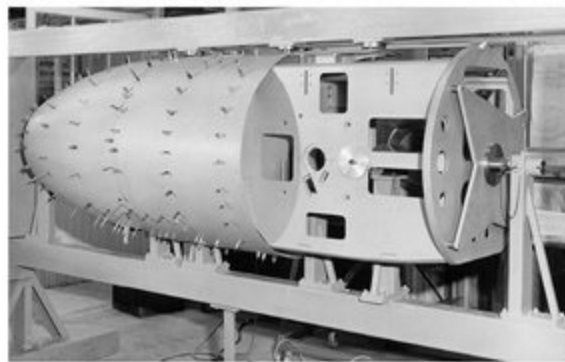
Mk 32 pod basic structure

Between these were five fabricated frames that accepted the pod's two main longerons on either side of the structure, and aft of the larger bulkhead were two machined side plates for the hose drum, the aft end of which were attached to the rear fabricated frame of the pod. A main forged top beam was secured to the structure, which formed the sole-plate for the pod's fuel, electrical interface and aircraft attachment lug. Forward and aft of the attachment were two spigots for accepting the forward, aft and side loads that were applied to the pod in flight. The complete structure was skinned with light-alloy skinning riveted in position. To achieve the skinning, two jigs were required. The first accepted the basic structural components, as shown below, then one side of the structure was skinned, as shown above right. Once this was completed, the pod was removed to a second jig for final

skinning, as shown.



Mk 32 pod structure prior to skinning



Mk 32 pod skinning process



Mk 32 pod final skinning

A rear fairing was eventually added to the assembly, which again was of a monocoque construction, and comprised a drogue stowage tunnel to accept the reception coupling and collapsible drogue, beneath which the contact lights were located. The two Red contact lights were in the centre, then at the port side of these the two Amber lights, followed by the two Green lights on the starboard side.

Mk 32 pod contact lights and drogue stowage



The design and manufacture of components having been completed, the overall concept of the Fuel-draulic system was as shown in Figs 283 and 284.

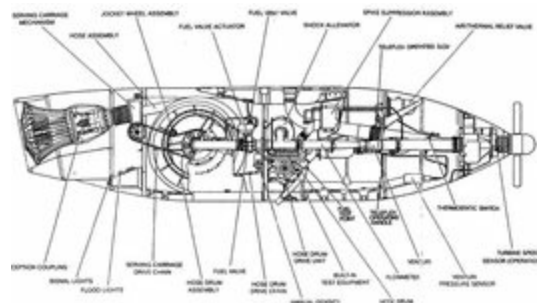


Fig. 283. Mk 32 air refuelling pod, starboard side

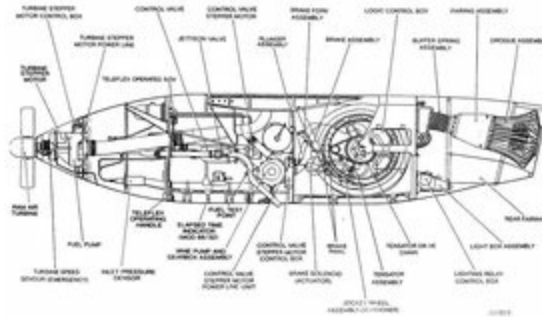


Fig. 284. Mk 32 air refuelling pod, port side

The operator's control panel (Fig 285) was designed to the same envelope as the Mk 20B. The reason for this was that in the original concept the new refuelling pod was a direct replacement of the Mk 20B on the Victor tanker. It was therefore necessary that the new panel should be capable of being installed at the operator's position in the Victor as a direct replacement.

The panel had the following indicators and switches, which provided the operator with not only the control, but also an indication of the sequences through the refuelling operation.

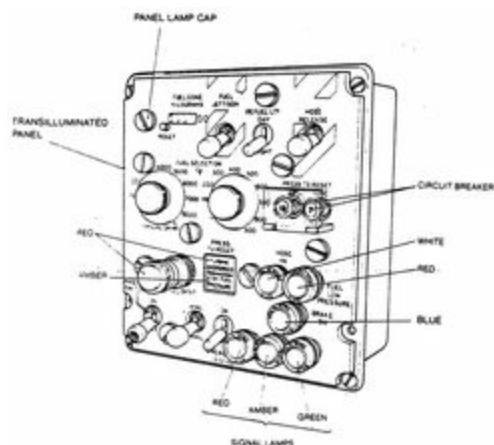


Fig. 285. Mk 32 air refuelling pod control panel

At the top of the panel to its left-hand side was the 'Fuel

gone' counter and reset button annotated in kilograms, which provided the operator with a visual indication of the total quantity of fuel that had been transferred, during one or more refuellings.

To the right of the counter were three switches, the first of which was the fuel-jettison switch that operated the fuel-jettison valve within the pod's fuel system. The second was the Day/Night switch that either dimmed or brightened the contact lights. The third was the refuelling hose-jettison switch that when selected energized the solenoid on the hose-release mechanism within the hose drum.

Beneath the 'Fuel gone' counter were two fuel-transfer rotary selection switches. The left-hand switch selected the quantity of fuel in thousands of kilograms, and had the manual selection; the second switch selected the quantity of fuel in hundreds of kilograms. Thus, to transfer 4,200 kilograms, the first switch was selected to 4,000 and the second to 200. During the fuel transfer the 'Fuel gone' counter counted up and the selection switches automatically counted down until the preselected quantity of fuel had been transferred. When the switches reached the zero position the fuel shut-off valve was signalled to 'CLOSE' and the vent valve to 'OPEN'. It also de-energized the turbine stepper motor, allowing the blades to move to the feathered position, simultaneously selecting the GREEN contact light to 'OFF' and the AMBER contact light to 'ON', thereby signalling the receiver aircraft that it had received the preselected quantity of fuel.

It was important not to rotate the fuel-selection switches in a clockwise direction once the fuel transfer had commenced. This action opposed the operation of the solenoids that rotated the switches from their preselected position back to zero. The switches were driven by pulse signals derived from the logic box, consequently possibly causing damage to the switches by arcing occurring when they were in certain positions. If it was necessary to increase the quantity of fuel

to be transferred once the selection had been made, the operator had to wait until the count-down had reached zero, and then a new selection could be made.

When selecting 'MANUAL' on the left-hand switch, this provided a continuous transfer of fuel to the receiver aircraft until it was totally refuelled. In this sequence, as the receiver was full, the fuel pressure would increase at the throat of the venturi, thus signalling via the pressure sensor that the turbine stepper motor was to be de-energized, thereby moving the blades to the feathered position and removing the fuel pressure and flow. However, the fuel shut-off valve remained 'OPEN' and the vent valve closed with the AMBER contact light 'ON'. If the operator concluded that sufficient fuel had been transferred he would select zero on the switch, which automatically closed the fuel shut-off valve and opened the vent valve, simultaneously signalling the GREEN contact light to 'OFF' and the AMBER to 'ON'. To the right of the fuel-selection switches were two guarded electrical circuit breakers, which were a protection for the panel's electrical supply.

Below the fuel-selector switches a RED fuel overheat light was located. This provided an indication that the fuel was overheating in the fuel pump's outlet. This permitted the operator to jettison the fuel, thereby introducing cold fuel from the parent aircraft's system, and allowed the system to be shut down. If the overheating continued, the tanker aircraft's fuel supply was closed, and the fuel-jettison valve in the pod 'OPENED', thus draining the fuel contents and allowing the fuel pump to seize.

On the right of the overheating light were the turbine overspeed and high-fuel-pressure indicator-switches.

The turbine switch was only illuminated if an overspeed occurred, and was coloured RED. To recover the sequence it was only necessary to depress the switch, which automatically de-energized the turbine stepper motor, the

blades moving to the feathered position; once the speed was reduced, the stepper motor was automatically re-energized, the blades moved to Fine pitch, and the turbine speed increased to normal.

The high-fuel-pressure switch was only illuminated if a sustained high fuel pressure occurred and the switch was coloured AMBER; again it was necessary to depress the switch for the system to recover.

If either of these sequences did not respond it was important that the emergency signal switch was selected, illuminating the RED contact light, thereby informing the receiver that there was a problem so that he could carry out an emergency breakaway.

To the right of these switches were the 'HOSE IN' white light, which indicated that either the hose was stowed, or when flashing the hose was moving in either the 'Trial' or 'Wind' sequences.

Next to this was the low-pressure fuel-pump-inlet RED warning light. This could be caused by a failure if the parent aircraft's fuel system had a failure. If it was sustained the operator had to shut down the refuelling pod and abort the operation. Beneath these two indicator lights was the BLUE brake light, which gave an indication when illuminated that either full trail or the parking brake had been applied.

Below and to the right were three switches: first the pod's master switch, which when selected applied the necessary electrical power to the pod's systems; the second the 'Trail'/'Wind' switch, which when selected was indicated by the WHITE flashing light in either sequence; the third was the emergency signal switch, which could be selected manually at any time during the refuelling operation; this illuminated the RED contact light informing the receiver pilot that there was a problem, and that he should either break contact or stand off.

Adjacent to these three switches were the RED, AMBER and GREEN contact lights indicating the state of the operation.

The operation of the refuelling pod was as follows:

Operator's action	Pod functional sequences and panel indications
Master switch 'ON'	Red contact light 'ON' Blue brake light 'ON' White hose light 'ON' Turbine blade-pitch stepper motor de-energized. Hose-drum control-valve stepper motor de-energized, valve sleeve in aft position.
Trail/Wind switch to 'TRAIL'	Turbine stepper motor energized, blades moving towards Fine pitch, and increasing speed. Hose-drum parking-brake solenoid de-energized, brake remaining engaged due to mechanical lock, reception coupling buffer spring providing the hose tension. Turbine reaches approximately 3,000 rpm, causing the fuel pump to provide a fuel pressure to be applied to the fueldraulic motor via the hose-drum control valve in the 'WIND' direction, thereby rotating the hose drum against the hose tension and releasing the

parking brake.

BLUE brake light 'OFF'

Hose ejected from pod via buffer spring
Turbine stepper motor de-energized.
Blades move to the feathered position.
Hose-drum control-valve stepper motor energized, moving its sleeve forward to the 'TRAIL' position, the hose trailing

WHITE light flashes, indicating hose trailing, after 3 feet of hose had been trailed. Hose trailing speed monitored by speed sensor on hose-drum drive unit, automatically adjusting the hose-drum control-valve sleeve to maintain 4 feet/sec hose trailing speed. This was signalled via the logic box and produced through both the operational and emergency pulses within the logic box. If the operational signal indicated that the trail speed was less than 3.6 ft/sec or more than 4.2 ft/sec, the stepper on the control valve automatically corrected the speed by moving the sleeve to the correct position. If the emergency signal indicated a speed of more than 5 ft/sec, the stepper motor was de-energized, causing the hose to trail at the minimum speed dictated by the sleeve valve's bleed holes. After 3 seconds the stepper motor was energized, moving the valve's sleeve to the TRAIL position, thereby controlling the trailing speed. During the trailing sequence the Tensator springs were transferred from their bobbins to the

centre hub after 15 feet of hose had been trailed. When the hose reached 5 feet from the full trail, a cam on the Tensator motor, operated by the two spring-loaded roller arms acting on the springs, switched the refuel switch inhibiting the WHITE light, the RED contact light to 'OFF', and the AMBER contact light to 'ON'. When the hose drum reached one revolution from the full trail, the cam mechanism on the Tensator motor overrode the full-trail brake plunger, and the brake-pawl mechanism was actuated, engaging the drum's brake rim, and finally engaging the abutment.

Select the fuel quantity to be transferred or to manual transfer

Receiver aircraft makes contact with reception coupling and drogue.

The receiver pushes the hose in approximately 5 feet, the Tensator motor winding the hose onto the drum but maintaining a hose tension, the drive-unit gearbox free-wheeling via the sprag clutch, the receiver being capable of moving in up to 33 feet max. maintaining the same Tensator response.

After the hose drum had made one revolution in the 'WIND' direction, the cam mechanism on the Tensator spring motor moved the full-trail brake to the 'OFF' position, switching the BLUE brake light to 'OFF' the refuel switch opening the fuel shut-off valve and closing the vent valve, which automatically switched the AMBER light to 'OFF' and the GREEN

contact light to 'ON', the latter informing the receiver pilot that the fuel was being transferred. Once the signal from the fuel flowmeter indicated 18 kg/min, the turbine stepper motor was energized, moving the blades to the fine-pitch position, so that the turbine's speed was increased and the fuel transfer commenced under pressure control. During the transfer, the fuel pressure at the reception coupling was maintained at 50 psi, irrespective of the flow. The venturi pressure sensor in the system monitored the pressure and signalled any changes between 46 and 55 psi. Thus the turbine stepper motor would change the blade-pitch angle accordingly. However, if 55 psi was maintained for more than two seconds, the stepper motor was de-energized, and the AMBER 'HIGH PRESSURE' warning light on the control panel was signalled 'ON'. The stepper motor would remain de-energized and the light 'ON' until the high-pressure switch was reset, when normal operation would resume unless the high pressure prevailed. If the pressure at the venturi exceeded 65 psi for more than one second, the AMBER light on the control panel would again be signalled 'ON', and the turbine stepper motor de-energized, so that the fuel flow ceased again until the high-pressure switch was reset. When transferring fuel to a high-rate-of-flow receiver, it was possible that the pressure-control system was unable to maintain the 50 psi at the reception

coupling, and the turbine would reach its maximum rpm of 6,900. In this event its speed control would be the primary factor rather than the pressure control. If during a fuel transfer the inlet pressure fell to between 3 and 5 psi, a signal from the inlet-pressure sensor effected a reduction in turbine/fuel pump speed. If the pressure continued to fall, the turbine blades would be feathered as the stepper motor would be de-energized, and the low-pressure warning light on the control panel would be 'ON' When the inlet pressure recovered, the turbine blades would be unfeathered by the stepper motor being energized.

Receiver aircraft accepted total selected fuel transfer, or had been totally refuelled via the 'MANUAL' selection

GREEN contact light 'OFF'. AMBER contact light 'ON'

If the quantity of fuel to be transferred was selected, the signals for the change-over of the contact lights was derived from the fuel-selector switch, which closed the fuel shut-off valve and opened the vent valve when the totalizer indicated that the transfer was complete.

Also the turbine stepper motor was de-energized the blades moving to the feathered position. Similarly, if 'MANUAL' had been selected, it was necessary to select 'ZERO', whereupon the change-over occurred.

Receiver aircraft reduced speed to extend the refuelling hose to the full-trail

position. As the hose reached 5 feet from full trail, the refuel switch signalled the fuel shut-off valve to close

and open the vent valve, if it had not signalled previously, as in a 'BRACKET' refuelling operation.

Receiver aircraft broke contact.

AMBER contact light remained 'ON' in readiness for a further refuelling. BLUE full-trail brake light 'ON'.

Select 'WIND' on control panel

Turbine and hose-drum control-valve stepper motors energized. Turbine blades moved to fine pitch, speed increased to 6,000 rpm, hose-drum control-valve sleeve moved to aft position, allowing fuel pressure to be applied to the fuel hydraulic motor in the 'WIND' direction. AMBER contact light 'OFF'.

RED contact light 'ON'.

BLUE brake light 'ON'.

Hose drum rotated in 'WIND' direction; after one revolution the full-trail brake was mechanically driven by the Tensator roller arms to 'OFF', and the cam switched the full-trail BLUE light to 'OFF'.

WHITE light flashed, indicating hose moving. When the hose reached the PRE-STOW position the magnetic shunt on the serving carriage signalled the turbine

stepper motor to deenergize the blades, moving to the feathered position and removing the rewind power to the fueldraulic motor.

Concurrent with the de-energizing of the stepper motor, the solenoid on the parking brake was energized, enabling the brakes' pawl to engage the hose drum's abutment ratchet. BLUE brake light 'ON' and the WHITE light ceased flashing, remaining 'ON' to indicate hose stowed. With no fuel pressure acting on the fueldraulic motor, the hose drum rotated slightly in the 'TRAIL' mode under the influence of the reception coupling buffer spring, thus mechanically locking the parking-brake pawl in the brake 'ON' position.

The operator had to ensure that the 'TRAIL/WIND' switch was left at 'WIND' in readiness for the next operation

Emergency operations

There were several emergency functions available to the operator of the equipment other than those designed in as safety features; these were as follows:

Hose jettison

It was necessary to have the refuelling hose at the 'FULL TRAIL' position before actuating the hose release mechanism. When the hose release was selected on the control panel it energized the solenoid within the assembly, rotating its shaft and thus releasing the jettison unit's shaft under its spring pressure. Two simultaneous operations occurred: the hose release mechanism was actuated, and the detent mechanism was engaged. The release of the hose resulted in the removal of the trailing components, i.e. the hose, the reception coupling and drogue. The consequence was an instantaneous reaction by the wound-up Tensator springs. However, the detent prevented any movement and the springs remained on the hub.

In operating the hose release switch it was essential that the switch was not held permanently 'ON', as the solenoid was not continuously rated. It was also important that prior to the resetting of the hose release mechanism a hose-drum gag should be fitted to prevent any rotation of the drum.

Fuel jettison

Fuel could only be jettisoned from the pod when the refuelling hose was fully trailed or stowed. On the selection of fuel jettison on the control panel, it signalled the actuator on the fuel-jettison valve to 'OPEN'; simultaneously the turbine stepper motor was energized, moving the blades towards the 'Fine' pitch position, thus increasing the fuel pressure. The turbine would increase its speed to 6,000 rpm, thereby pumping the fuel overboard. On completion of the operation, when the selection was reversed, the valve closed and the turbine stepper motor de-energized, the blades moving to the feathered position.

Emergency signal

The function of the emergency signal switch was to provide a disengagement of stand-off signal to the receiver pilot, and

could be selected during a refuelling operation in the event of an emergency occurring with the equipment.

A new item of equipment was incorporated within the pod, which enabled the system to be checked out through its electronic circuits on the ground.

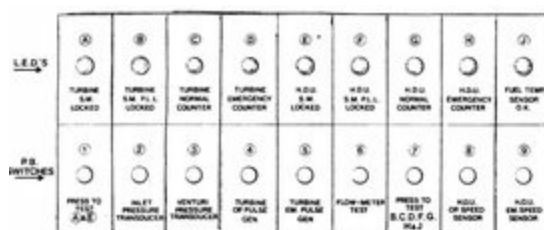


Fig. 286. Mk 32 built-in test equipment panel

This was the Built-In Test Equipment (BITE) unit, as shown in Fig 286, and was located on the starboard side of the pod above the hose-drum drive unit.

Access to the BITE was through a panel on the starboard side of the structure forward of the hose-drum bay. Access to the hose-drum bay was achieved through large opening panels providing access to the fuel and vent valve on the starboard side, and to the Tensator spring motor, logic box and slip rings through the port. The rear fairing of the pod was completely removable, providing access to the reception coupling and drogue and the contact lights. A further removable panel was located at the centre and bottom of the main pod structure, providing access to the fuel-system components. Access to the turbine and fuel pump was through the removable nose-cone fairings.

Thus the Mk 32/2800 air refuelling pod had become a practical piece of equipment. However, the mechanical achievement was the Tensator spring motor, which provided such a good hose response that the original limit of 5 knots overtaking speed for a receiver aircraft making a contact was deleted. During test flying on the de Havilland Sea

Vixen, an overtaking speed of 18 knots was achieved with no hose whip.



Mk 32 air refuelling pod

After the ten years of developing the refuelling pod it was fortunate that everybody kept a sense of humour, as when above the author was asked to 'Wind up the prototype pod.' (above)

Then the final achievement was the pod being incorporated on the Vickers VC10 three-point tanker:



Mk 32/2800 air refuelling pod on Vickers VC10 tanker

CHAPTER TWENTY-EIGHT

Mk 17B Air Refuelling Package

The Mk 17B air refuelling package was identical to the Mk 17 package fitted to the K Mk 1 and K Mk 1A Victor tankers, but to suit the AC electrical system in the Mk 2 aircraft.

However, prior to the modification of the package to accomodate an AC electrically powered drive unit, a design study was carried out into the feasibility of retaining the Mk 17 package. From the investigation it was found that the solution was by means of a transformer rectifier unit. Nevertheless, at the time of the investigation this was not deemed to be a practical solution. Since Flight Refuelling's investigation the Ministry of Technology had carried out a further investigation and found that there were two alternative possibilities for AC power being applied to the hose-drum unit of the package. The first was a lightweight transformer rectifier unit, and the second a direct replacement of the hose-drum unit's drive motor from DC to AC.

Flight Refuelling Ltd investigated these possibilities and found that Rotax Ltd manufactured a transformer rectifier unit of a reduced size and weight. This unit was in use on the SRN4. Hovercraft. Though this unit was favourable for supplying the necessary DC supply, the power requirement for the hose-drum unit was higher than that on the Hovercraft, therefore the rating of the unit was also increased. The unit would also require a supply of cooling air to be fed to it to permit the power required for the hose-drum unit to be maintained. Furthermore, consideration had

to be given to the overall design and development costs for the conversion of the Victor Mk 2 aircraft into a tanker.

Mk 17B refuelling package assembly



An investigation was also made into the possibility of using a direct replacement 200 V AC motor in lieu of the existing 112 V DC motor employed on the Mk 17 hose-drum unit. It was thought that Rotax Ltd had such a motor, with the part no. LK.2218. However, this was in fact found not to be a complete motor, but a stator and rotor assembly. To make this unit suitable for powering the MK 17 hose-drum unit, further design and development would be necessary, since a housing with a cooling fan and gearing would have to be designed and manufactured. With the exiting hose-drum unit's primary drive reduction gearing being retained, the rpm of the LK.2218 rotor and stator would exceed that permitted. To overcome this problem it was essential to incorporate a gear reduction within the motor.

Eventually a new continuously rated 15 h.p., 200 V, 3-phase, 400 Hz, star-connected induction motor drive motor was developed. This then changed the identity of the refuelling package to the Mk 17B for use on the Victor Mk 2 tanker conversion.

The only other minor changes were that the fuel-jettison system on the package was deleted, and a defuelling connection was added upstream of the main fuel and vent valves. The latter was to permit the aircraft's transfer tanks to be defuelled into ground tankers, or to enable the aircraft to be used as a ground tanker to refuel other aircraft.

The package's control panel was similar to that fitted to the Victor K1/1A aircraft, but having a hose tension and AC indicator with a suitable shunt located on the hose-drum unit.

The Mk 17B refuelling package is shown being assembled opposite.

The Victor K Mk 2 tanker refuelling a Tornado is seen below.

Victor K Mk 2 tanker refuelling a Tornado



CHAPTER TWENTY-NINE

English Electric Canberra B.2 Tanker

Following an in-house investigation carried out at the British Aircraft Corporation (now British Aerospace), Warton, in which Flight Refuelling Ltd and Marshalls of Cambridge were involved, at a meeting at Marshalls on 16 May 1975 it was concluded that an in-depth design study should be carried out to convert the Canberra B Mk 2 into a single-point tanker, the plan of which is shown in [Fig 287](#), to support the Jaguar aircraft in service with overseas governments. The design would carry either the Mk 20B or Mk XXXII refuelling pod, and was to be a private-venture task involving the three companies. The reasoning behind the selection of the two refuelling pods was that the former was readily available, and the latter, although an improved design, was still under development at the time of the study. Additional fuel capacity was to be incorporated using a Jaguar drop-tank mounted beneath the aircraft's starboard wing, and a modified standard bomb-bay tank.

The fuel system ([Fig 288](#)) was the basic Mk 2 system, comprising the standard three fuselage tanks, with the wingtip tanks feeding the aft of the three.

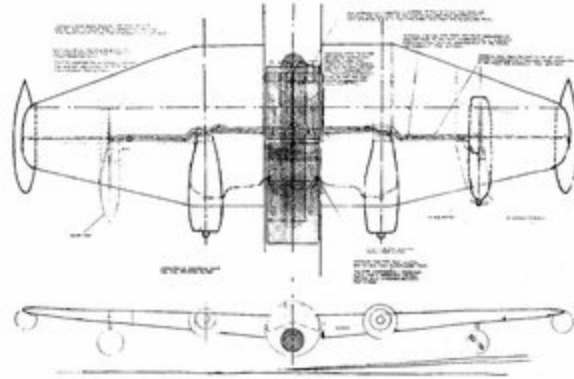


Fig. 287. Canberra Mk B.2 single-point tanker proposal

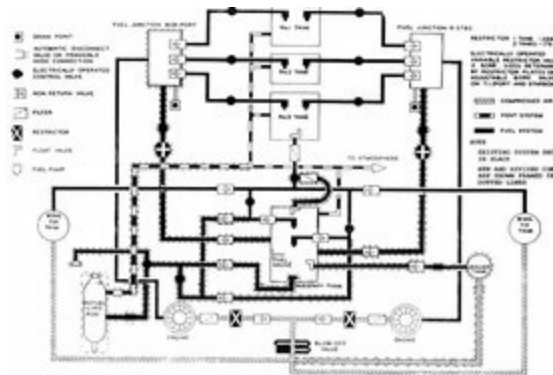


Fig. 288. Canberra B.2 tanker fuel system

These were to be augmented by the addition of:

1. One 650-imperial-gallon (2,925 litres) overload tank in the bomb-bay ([Fig 289](#))
2. One 250-imperial-gallon (1,125 litres) Jaguar drop-tank fitted beneath the aircraft's starboard wing and outboard of the starboard engine.

The system was to be capable of transferring 1,400 imperial gallons (6,300 litres) of fuel at 140 imperial gallons (630 litres) per minute. The maximum fuel transfer that the system could have achieved was 2,000 imperial gallons (9,000 litres), but it was not used to prevent the possibility of engine-fuel starvation occurring. The total quantity of fuel

available, together with the various rates of flow from the fuel tanks, were:

The basic aircraft tanks and additional tanks would supply fuel to the refuelling pod located beneath the port wing.

The following additional fuel line connections completed the system:

1. Fuel feed lines from both port and starboard aircraft fuel junction boxes to the auxiliary tank (bomb-bay)
2. Fuel feed lines from the Jaguar drop-tank to the auxiliary tank and to the wingtip fuel line.
3. Fuel feed lines from the auxiliary tank to the refuelling pod, together with vent lines from the pod to the aircraft's vent system.
4. Facility to switch the wingtip tank lines to No. 3 fuselage tank into the auxiliary tank.
5. Facility to switch the two existing fuel pumps in the auxiliary tank to the refuelling pod supply lines, either to boost the feed from the new pump installation, or provide an emergency source for fuel jettison should the latter fail

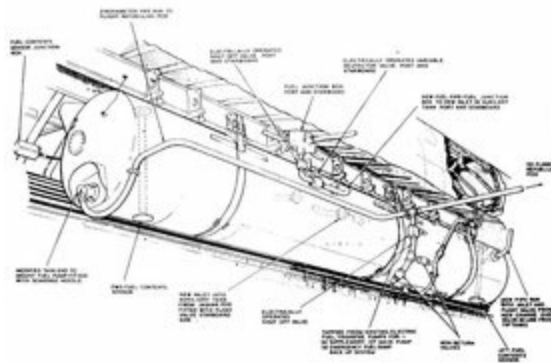


Fig. 289. Canberra B.2 bomb-bay overload fuel tank

Fuel tank	Capacity (gallons)	Capacity (litres)	Capacity (lb)	Flow Rate (per min)
No. 1 Fuselage	520	2,340	4,160	50
No. 2 Fuselage	317	1,427	2,536	50
No. 3 Fuselage	540	2,430	4,320	50
Wingtip tanks (2)	488	2,196	3,904	14
Jaguar drop-tank	250	1,125	2,000	15
Auxiliary tank	650	2,925	5,200	140
TOTALS	2,765	12,443	22,120	319

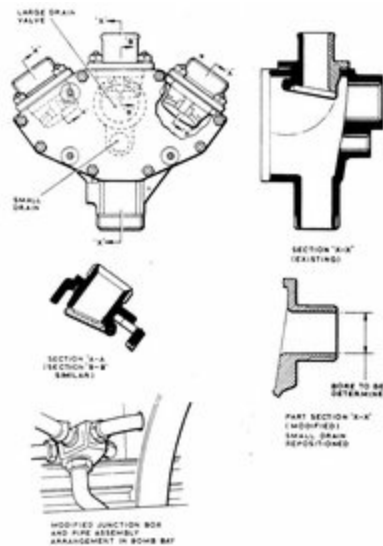


Fig. 290. Fuel junction box

The fuel lines from the junction boxes (Fig 290) to the auxiliary tank were to be of 1½ inches diameter. A motorized fuel shut-off valve, and variable restrictor valves controlled by the pilot and refuelling operator respectively, were to be incorporated in the fuel lines.

The restrictor valves were to control the fuel flow from the junction boxes dependent upon the fuel emanating from a single or combined tank. They were to be a modified form of Saunder's ball-type valve, with internal bores at 90 degrees, the sizes of which were to be determined in a trial installation. A non-return valve was also to be located in the fuel lines prior to entering the tank.

Owing to the confined condition of the bomb-bay when the auxiliary tank was installed, and to ensure that the aircraft's bomb-bay doors were not impeded in their operation, the necessary fuel pipe installations would be carefully located.

The fuel line from the Jaguar drop tank to the auxiliary tank was to be of 2.00 inches (51 mm) diameter. This would run from the new inlet in the tank, fitted with a float-operated shut-off valve, through an aperture in the side of the fuselage and thence to the starboard wing just aft of the spar.

Similarly, a new pressure line would be tapped into the existing pressure system at the blow-off valve located on the centre line of the bomb-bay. This line would then extend out of the fuselage into the starboard wing, together with the wingtip lines.

The auxiliary tank and pressure fuel lines would extend along the rear face of the spar (together with existing fuel services) beneath the engine and thence to Rib 5, which would necessitate a slight adjustment to the existing pipes. At Rib 5, both lines would pass through the inner lower wing surface, terminating at the Jaguar drop-tank.

Inside the Jaguar drop-tank's mounting pylon the fuel lines would incorporate an automatic disconnect shut-off valve to permit the tank to be jettisoned.

The fuel line extending from the auxiliary tank to the refuelling pod was also to be of 2.00 inches diameter. This line would extend aft from the new transfer pump at the forward end of the tank alongside the tank to a position immediately aft of the rear spar. At this point it would pass through an aperture into the port wing. Similarly a vent line connected to the existing aircraft venting system at the rear end of No. 3 aft fuselage tank would pass into the bomb-bay and run through an aperture into the port wing, and follow the wingtip fuel lines to a station aft of the spar.

The auxiliary tank vent lines would extend along the rear face of the spar (together with the existing fuel lines) beneath the engine and thence to Rib 5. The fuel lines would then pass through the rear spar and out of the wing's lower surface into the pylon, and thence to the refuelling pod. The vent lines would follow a similar route, but would remain aft of the rear spar. A similar jettison facility to that of the Jaguar drop-tank would be incorporated.

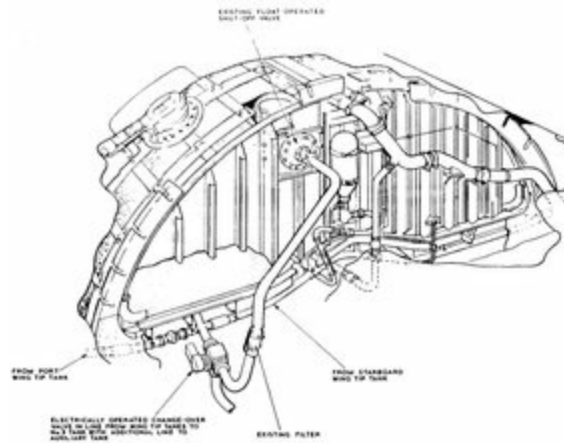


Fig. 291. No. 3 rear fuselage fuel tank

The facility for switching the wingtip tanks to feed the auxiliary tank from No. 3 aft fuselage tank would be achieved as follows:

1. The incorporation of a motorized change-over valve in the existing transfer pipe at the rear of No. 3 aft fuselage tank, as shown in [Fig 291](#).
2. Extending a pipe from this valve, through a filter into a new inlet in the rear of the auxiliary tank, which could embody a float-operated shut-off valve to prevent overfilling.

Redesign of the fuel junction boxes would be necessary to ensure the provision of an adequate fuel feed between each box and the auxiliary tank. During the study it was found

that the large drain valve in the base of the junction box was not used, and the difficulty of connecting a hose to it because of the close proximity of the bomb-bay doors in the 'open' position. The boss on this face would have to be enlarged to cater for a larger pipe, which would extend to the auxiliary tank. The small drain hole would be repositioned.

Modifications to the auxiliary tank would be necessary to ensure adequate fuel feed to the refuelling pod. The tank would be a standard tank fitted to this type of aircraft in its bomb-bay, which was a welded cylinder with hemispherical ends, having baffles welded at intervals internally along its length. The tank would have to incorporate the installation of a large fuel pump, two sensors for fuel gauging, and four inlet ports, two of which would accommodate float-operated shut-off valves. The larger pump would be mounted on a plate that would be housed at the forward end of the tank. Though this would reduce the tank's capacity slightly, the method of installation kept the protrusion of the pump into the bomb-bay to a minimum. The pump would be mounted horizontally, and would include a scavenge nozzle to enable the maximum amount of fuel to be pumped prior to cavitation occurring.

The sensor units of the fuel-gauging system would be mounted vertically, one at each end of the tank and on its centre line; they each required two diametrically opposed mounting rings welded to the tank. Each of the four fuel inlets would also have a welded mounting ring.

The new, larger, fuel-transfer pump at the outset of the study was to be hydraulically powered; however, further investigation revealed a Plessey Type 6810 electrically driven pump to be preferable.

The fuel flow requirement of the refuelling pod at its inlet was 140 imperial gallons (630 litres) per minute at 4 psig (0.27 bar) inlet pressure, allowing for fuel-line losses from

The Jaguar drop-tank was to be installed to a modified Canberra TT.18 towed-target-pod wing pylon, as shown in [Fig 292](#), which would be located on the underside of the starboard wing outboard of the engine at Rib No. 5. A sole-plate serving as an adaptor would be fitted to the drop-tank, which in turn would also locate with the refuelling pod's attachments. The drop-tank, together with its adaptor sole-plate, would be capable of being lifted into position utilizing the existing ground equipment for the towed target pod.

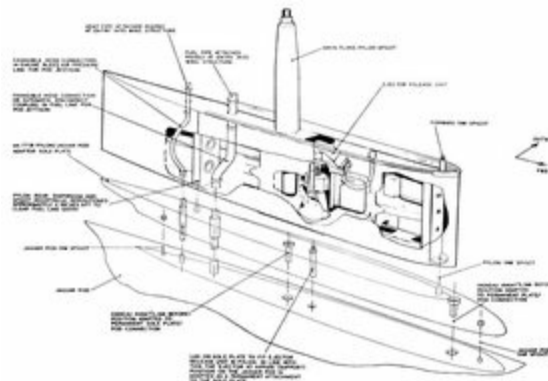


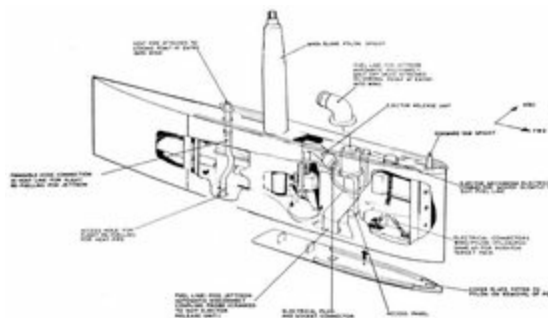
Fig. 292. Jaguar drop-tank wing pylon

Modifications to the pylon would consist of the inclusion of a frangible hose coupling in the fuel and vent lines to the aircraft's system. The location of the fuel-line coupling would necessitate moving the aft yaw spigot receptacle and its support diaphragm approximately 2.00 inches further aft. An automatic disconnect/self-sealing coupling was considered as an alternative to the frangible hose coupling, but this was rejected because of its overall diameter and close proximity

to Rib 5.

The Mk 20B or Mk 32 refuelling pod would be installed in a similar manner to the towed target pod, a modified Canberra TT.18 pylon being used, as shown in [Fig 293](#). Either pod would fit directly onto the pylon at Rib 5 on the port wing, as the yaw spigots and ejector-release mechanism attachments were the same. As in the case of the Jaguar drop-tank, the existing ground handling equipment could be used. Similarly the electrical connections between wing and pylon were compatible.

The alterations to the pylon would consist of the incorporation of a fuel line utilizing an automatic disconnect/self-sealing coupling. The coupling would be installed forward of the ejector release mechanism, which would necessitate relocation of the unit/wing pylon electrical connector.



[Fig. 293](#). Mk 20B or Mk 32 refuelling pod pylon

Provision would be made for strong points in the wing's lower surface to accommodate the automatic disconnect valve in the fuel line and the frangible hose connection in the vent line.

As for the auxiliary tank's fuel-contents gauges, the tank having the larger axis extending fore and aft on the aircraft's longitudinal axis, the fuel level in the tank would be affected considerably by the pitching attitude of the aircraft.

Therefore provision of an attitude-correcting type of fuel gauge was essential to enable the pilot and operator to be provided with accurate fuel-contents readings at the flight attitudes encountered during fuel transfer and jettison modes.

Conversely, the relatively small lateral pitch (roll) angles normally encountered would not have any significant affect on the accuracy of the gauging system, since the cross-section of the tank was circular and the diameter was much smaller, compared with its length.

Two systems were available that satisfied the required conditions:

1. Smith's Type 7
2. Flight Refuelling Ltd

The Smith's system incorporated two flanged-mounted cylindrical probes that would be located vertically in the tank and on its centre line, one at the front, the other at the rear. These probes, of the variable capacitance type, had no moving parts and offered high reliability. They transmitted signals to the gauges, located at the pilot's and operator's positions.

The Flight Refuelling Ltd system incorporated two flange-mounted cylindrical probes mounted in the same position and attitudes. These accommodated an external float, which moved with the fuel level and triggered internal switches, which in turn transmitted signals to the gauges.

For the jettisoning of fuel, an internal jettison facility through either of the refuelling pods was as follows:

Mk 20B refuelling pod:

50 imperial gallons (225 litres) per minute

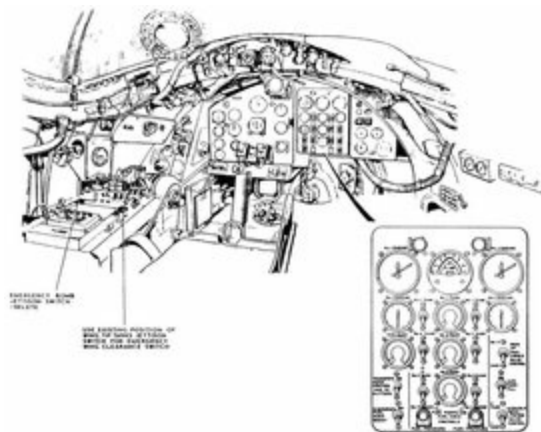
Mk 32 refuelling pod:

75 imperial gallons (338 litres) per minute

With this facility, which was only available with a refuelling pod installed, fuel could be jettisoned from the aircraft's complete system. However, should it be necessary to jettison the refuelling pod, the jettison facility would be eliminated. An alternative jettison system would be provided should it be found that it was essential. This new jettison system would include the incorporation of a motorized change-over valve located in the refuelling pod's fuel supply line, extending to an additional overboard outlet in the aircraft's lower wing surface outboard of the pod. This system would employ the new fuel pump attached to the auxiliary fuel-tank.

Should, however, the new fuel pump fail to operate, the fuel that was normally pumped by the two existing pumps at the rear of the auxiliary tank to the No. 3 aft fuselage tank could be diverted into the refuelling pod's supply line.

A switch, labelled WING CLEARANCE, mounted on the port console, as shown in [Fig 294](#), would enable the pilot to jettison the standard wingtip tanks, the Jaguar drop-tank and the refuelling pod simultaneously. This switch replaced the existing wingtip-tank jettison switch.



[Fig. 294](#). Canberra B.2 port console wing-clearance switch

To control the refuelling system two additional panels would be located at the navigator's position, as shown in [Fig 295](#)

these were the flight-refuelling-pod control panel and ancillary panel. These panels would be located directly below the air-position indicator panel, which would necessitate the removal of some of the GEE 'H' equipment.

The ancillary panel would incorporate a fuel-contents gauge for the auxiliary tank, and indicators connected to the pilot's engine control panel to show that the fuel flow had been selected to it, also indicating the requirement of the emergency fuel-jettison facility on the refuelling pod.

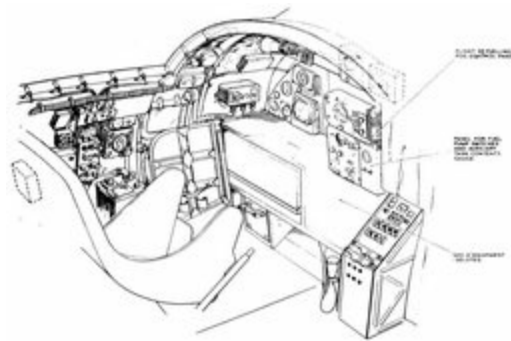


Fig. 295. Canberra refuelling operator's position

The switch previously mentioned, labelled WING CLEARANCE, would be suitably guarded to prevent inadvertent operation; it would be sited at the position occupied by the existing bomb-jettison or wingtip-tank switch (see [Fig 294](#)).

The other controls for the pilot would be incorporated on the engine instrument panel, which had to be modified, and would include the following:

1. Auxiliary tank fuel-contents gauge
2. Master switch, to control the transfer of fuel from the fuel junction boxes to the auxiliary tank
3. Restrictor-valve control switch, to operate the valve and control the rate of flow, thus preventing the possibility of engine fuel starvation during switching over of aircraft fuel-tanks

4. Wingtip fuel-tank diversion control switch, to divert wingtip fuel-tank feed to No. 3 tank aft fuselage tank directly to the auxiliary tank
5. Fuel-transfer control switch, to control the standard transfer of fuel from the auxiliary tank to No. 3 aft fuselage tank
6. Fuel-jettison/transfer switch, a guarded switch that diverted fuel being transferred from the auxiliary tank to No. 3 aft fuselage tank into the refuelling pod's supply line so as to maintain the fuel-jettison capability in the event of a transfer-pump failure.

Owing to the additional fuel capacity of the aircraft by the use of extra fuel-tanks to the existing B Mk 2 fuel system, it would be necessary to revise the aircraft's fuel-control drill to maintain balance. The following illustrates the new drill, together with variation of the duration of flight (note the capacity of the fuel-tanks has been stated previously):

1. Starting engines and taxi procedure:

Nos 1 and 2 fuselage tanks	pumps OFF
No. 3 aft fuselage tank	pumps ON
Auxiliary tank	pumps OFF

In this condition the wingtip tanks automatically feed No. 3 aft fuselage tank. The fuel used for these operations would be 163.5 imperial gallons (736 litres). On completion of this operation, prior to take-off the fuel-tank quantities would be:

No. 3 aft fuselage tank no change, i.e. 4,320 lb, 540 gallons

Wingtip tanks quantity reduced to 3,056 lb, 382 gallons

2. Take-off and climb to 2,000 feet altitude:

No. 1. fuselage tank pumps ON

No. 2. fuselage tank pumps ON

No. 3 aft Fuselage tank pumps ON

Auxiliary tank pumps
OFF

Wingtip tanks automatically feeding No. 3 aft fuselage tank.

At the completion of this sequence, after a period of four minutes' duration, fuel used would be:

112 gallons, 896 lb

Fuel state in tanks:

TANK	POUNDS	GALLONS	LITRES	ALTERATION
No. 1 fuselage tank	3,860	482.5	2,171	Reduced
No. 2 fuselage tank	2,237	280	1,260	Reduced
No. 3 aft fuselage tank	4,320	540	2,430	None
Wingtip tanks	2,755	344	1,548	Reduced

Climb and cruise to rendezvous to carry out a refuelling operation. Two cases were considered, Case A being of 15 minutes' duration, and Case B 4 minutes' duration.

The following were the fuel-tank states and quantity of fuel used:

Case A Fuel used for 15 minutes' duration with engine power at 60% (2,016 lb, 252 gallons)

TANK	POUNDS	GALLONS	LITRES	ALTERATION
No. 1 fuselage tank	3,860	482.5	2,171	None
No. 2 fuselage tank	2,237	280	1,260	None
No. 3 aft fuselage tank	3,984	498	2,241	Reduced
Wingtip tanks	1,075	134	603	Reduced

Fuel-tank sequences:

No. 1 fuselage tank pumps
OFF

No. 2 fuselage tank pumps
OFF

No. 3 aft fuselage tank pumps ON

Wingtip tanks automatically feeding No. 3 aft fuselage tank.

Case B

The procedure and fuel-tank dispositions would be as in Case A

The following were the fuel-tank states and quantity of fuel used

Fuel used at 60% engine power for 4 minutes (67.5 gallons, 540 lb)

At the end of this sequence the fuel tank states would be:

TANK	POUNDS	GALLONS	LITRES	ALTERATION
No. 1 fuselage tank	3,860	482.5	2,171	None
No. 2 fuselage tank	2,237	280	1,260	None
No. 3 aft fuselage tank	4,230	529	2,380	Reduced
Wingtip tanks	2,307	288	1,296	Reduced

Refuelling Operation

The operation would take ten minutes to complete, during which time 1,400 gallons would be transferred to a receiver. As for the take-off and cruise conditions, two cases were considered (A and B).

1. Contact by receiver aircraft.
2. Transfer of fuel until No. 2 fuselage tank was reduced to 1,250 lb, or 156 gallons, which had to be retained for overshoot and GCA on return flight. During this period, 2.78 minutes, 3,114 lb, or 389 gallons, of fuel would have been transferred.
3. Transfer of fuel until 1,600 lb, or 200 gallons, remained in No. 1 fuselage fuel-tank, which was necessary to maintain aircraft's CG limitation. During this period, 6.36 minutes' duration, 7,123 lb, or 890 gallons, would have been transferred.
4. Completion of fuel transfer, which was 0.86 minutes, giving a total of ten minutes of fuel transfer. In all, 963 lb, or 120 gallons, would have been transferred.

The total amount of fuel transferred would therefore be:

1.	3,114 lb	389 gallons
2.	7,123 lb	890 gallons
3.	963 lb	120 gallons
	<hr/> 11,200 lb	<hr/> 1,399 gallons

(Note: pounds accurate, gallons to nearest gallon)

During the refuelling operation 60% of engine power would be maintained. When contact had been made, an indication to this effect would be seen on the operator's refuelling-pod control panel. The procedure would then be:

1. The operator would start the fuel transfer from the refuelling pod.

Automatically energize the main transfer pump in the auxiliary tank. The operation of this pump was indicated on the operator's and pilot's engine control panels.

2. The pilot on receipt of the indication would:
 - a. Ensure that the auxiliary-tank fuel-transfer restrictor valve was in the two-tank position
 - b. Move the auxiliary-tank fill switch to 'ON', opening the shut-off valve in the line from the fuel junction boxes.
3. Move No. 2 fuselage-tank switch to 'ON'.
4. Move wingtip-tank feed from No. 3 aft fuselage tank to auxiliary tank. Completing the above actions would ensure the following:

No. 2 and No. 3 aft fuselage tank supplied fuel to the engines and the auxiliary tank, Jaguar drop-tank and wingtip tanks feeding fuel to the refuelling pod.

The first sequence was terminated after a period of 2.78 minutes, when 1,250 lb, or 156 gallons, of fuel was retained in No. 2 fuselage tank. The fuel-tank quantities in cases A and B would be:

CASE A

TANK	POUNDS	GALLONS	LITRES	ALTERATION
No. 1 fuselage tank	3,860	483	2,173	None
No. 2 fuselage tank	1,250	156	702	Reduced
No. 3 aft fuselage tank	2,997	375	1,683	Reduced
Auxiliary tank	4,333	542	2,439	Reduced
Wingtip tanks	767	96	432	Reduced
Jaguar drop-tank	1,666	208	937	Reduced

CASE B

TANK	POUNDS	GALLONS	LITRES	ALTERATION
No. 1 fuselage tank	3,860	483	2,173	None
No. 2 fuselage tank	1,250	156	702	Reduced
No. 3 aft fuselage tank	3,243	406	1,827	Reduced
Wingtip tanks	1,999	250	1,125	Reduced
Auxiliary tank	2,349	294	1,323	Reduced
Jaguar drop-tank	904	113	508	Reduced

During this sequence the fuel transferred and consumption of fuel would be:

Total fuel transferred 7,123 lb, or 890 gallons

Total fuel consumed, including that transferred, 7,972 lb, or 996.5 gallons

The third sequence of refuelling covered a period of 0.86 minutes, which was the balance remaining to complete the ten-minute refuelling operation when 1,400 gallons would have been transferred (140 gallons per minute).

When the pilot received the indication that No. 1 fuselage tank quantity was down to 1,600 lb, or 200 gallons, he would carry out the following:

1. Move the auxiliary tank fuel-transfer restrictor valve to the single-tank position.
2. Move No. 1 fuselage-tank switch to 'OFF'.

3. This ensured that No. 3 aft fuselage tank supplied fuel to the engines and auxiliary tank, and to the refuelling pod.

At the conclusion of the refuelling operation the fuel-tank quantities would be:

TANK	POUNDS	GALLONS	LITRES	ALTERATIONS
Case A				
No. 1 fuselage tank	1,600	200	900	None
No. 2 fuselage tank	1,250	156	702	None
No. 3 aft fuselage tank	470	59	266	Reduced
Wingtip tanks	0	0	0	Reduced
Auxiliary tank	1,702	213	959	Reduced
Jaguar drop-tank	800	100	450	Reduced
Case B				
No. 1 fuselage tank	1,600	200	900	None
No. 2 fuselage tank	1,250	156	702	None
No. 3 aft fuselage tank	716	90	405	Reduced
Wingtip tanks	1,197	150	675	Reduced
Auxiliary tank	1,737	217	977	Reduced
Jaguar drop-tank	800	100	450	Reduced

During this phase of the operation the transfer and consumption of fuel would be:

Total fuel transferred 963 lb, or 120 gallons

Total fuel consumed, including transfer, 1,079 lb, or 135 gallons

On completion of the refuelling operation, the refuelling operator would terminate the transfer of fuel to the refuelling pod, which automatically closed the shut-off valve in the transfer lines from the fuel junction boxes to the auxiliary tank. At the same time the pilot would have received an indication of this and would then move the auxiliary-tank switch to OFF.

When the fuel transfer had been completed, the quantity of fuel remaining, excluding the allowances for the aircraft to return to base, would be illustrated as:

Case A 1,984 lb, or 248 gallons

Case B 4,900 lb, or 613 gallons

Thus the maximum totals available for a refuelling transfer would be:

Case A 13,148 lb, or 1,644 gallons

Case B 16,100 lb, or 2,013 gallons

If a continuous transfer of fuel in excess of 11,200 lb, or 1,400 gallons, was considered with a delivery flow rate of 1,120 lb/min, or 140 gallons/min, it had to be noted that the auxiliary tank would be empty before the Jaguar drop-tank and the wingtip tanks (Case B) were capable of transferring fuel to it. This would be due to the slow rate of these tanks when combined with No. 3 aft fuselage tank compared with that from the auxiliary tank.

The problem, however, could be overcome by the adoption of a lower fuel transfer rate while refuelling the receiver, or allowing a time interval for the fuel to be transferred while the wingtip tanks fed fuel to the auxiliary tank.

The pylon to carry the refuelling pod was to be similar to that employed on the TT.18 Canberra, which carried a towed target pod beneath each wing. However, due to the increased loads incurred by the refuelling pod, modifications would be necessary to meet the new requirements. The following, therefore, was necessary:

1. Pod-to-ylon locations at spigot housing attachments
2. Pylon forward yaw spigot top diaphragm to improve bearing capability
3. Pylon wing spigots to improve bending and shear capability
4. Pylon/wing at Rib 5 to make provision for fuel pipe and quick-release fasteners to the refuelling pod
5. Sole-plate complete redesign to cover Jaguar drop-tank installation

The above modifications therefore made it necessary for new

wing pylons to be designed and manufactured.

The control panel for the refuelling pod was to be the standard panel used for either the Mk 20B or Mk XXXII pods. It would be mounted at the navigator's position, adjacent to the fuel-pump switches and auxiliary-tank-contents gauge.

Nevertheless, after this comprehensive study had been completed, no overseas governments made use of the Canberra tanker aircraft. It is important that the overall study between the three companies indicated the cooperation that was achieved.

CHAPTER THIRTY

Vickers VC10

Three-Point Tankers

Conversion of the VC10 commercial airliner into a three-point tanker commenced at Filton, Bristol, in April 1978. The conversions totalled nine aircraft, five Standard aircraft being designated as K Mk 2 and four Super aircraft designated as K Mk 3. Each aircraft was to have three refuelling units, one beneath each wing, and one in a specially constructed bay in the underside of the rear fuselage. A typically converted aircraft is shown here, refuelling an F-4 Phantom.

The five Standard aircraft were originally Vickers Type 1101 for British Overseas Airways, and subsequently operated by Gulf Air of the Middle East, while the four Super aircraft were Vickers Type 1154 operated by East African Airways.



Vickers VC10 three-point tanker

The following is a brief history of the nine aircraft conversions:

Vickers Type	Civil Registration	First Flight	Delivery Date	Airline	RAF Tail No.	Tanker Mark
1101	G-ARVL	02-06-64	16-06-64	BOAC/BA Gulf Air	ZA.140	K Mk 2
1101	G-ARVG	17-09-63	12-06-64	BOAC/BA Gulf Air	ZA.141	K Mk 2
1101	G-ARVI	20-12-63	22-04-64	BOAC/BA Gulf Air	ZA.142	K Mk 2
1101	G-ARVK	28-03-64	02-05-64	BOAC/BA Gulf Air	ZA.143	K Mk 2
1101	G-ARVC	21-03-64	01-12-64	BOAC/BA Gulf Air	ZA.144	K Mk 2
1154	SH-MMT	12-10-66	31-10-66	East African Airways	ZA.147	K Mk 3
1154	SY-ADA	21-03-67	31-03-67	East African Airways	ZA.148	K Mk 3
1154	SX-UVJ	19-04-69	30-04-69	East African Airways	ZA.149	K Mk 3
1154	SH-MDG	16-02-70	28-03-70	East African Airways	ZA.150	K Mk 3

The three-point concept was to employ the Mk XVIIB refuelling package as used on the Victor Mk 2 at the centre line or fuselage position, and either the Mk 20B or the new Mk XXXII refuelling pod at the wing stations. The installation was also to have additional fuel tanks to augment the aircraft's existing fuel capacity. The commercial Standard Type 1101 had a capacity of 17,925 imperial gallons (80,662 litres, or 64 tons) in four integral wing tanks, and a centre-section transfer tank. The Super version Type 1154 had an increased capacity of 19,365 imperial gallons (87,142 litres, or 69 tons), which used the same wing and centre-section transfer tanks, plus an additional tank in the aircraft's fin, both types being supplemented by five additional cylindrical fuselage tanks.

The Standard, or VC10 K Mk 2 tanker is shown in [Fig 296](#), and the Super, or K Mk 3, is shown in [Fig 298](#).

[Fig. 296](#). Vickers VC10 K Mk 2 tanker

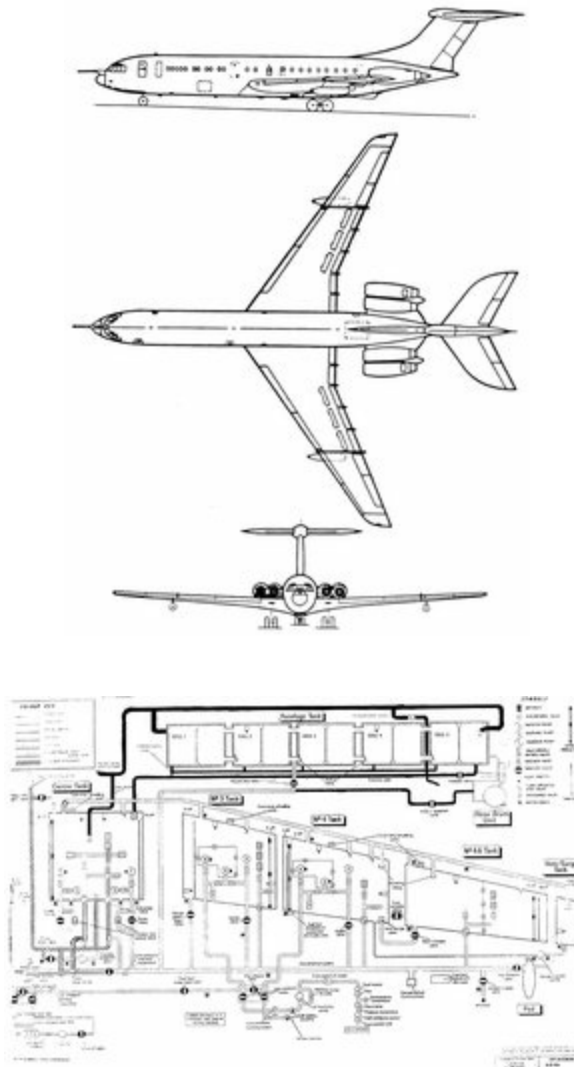
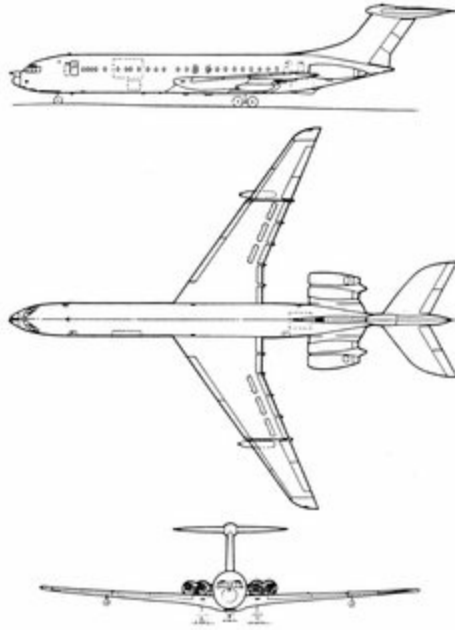


Fig. 297. VC10. Three-point tanker typical fuel system

Fig. 298. Vickers VC10 K Mk 3 tanker



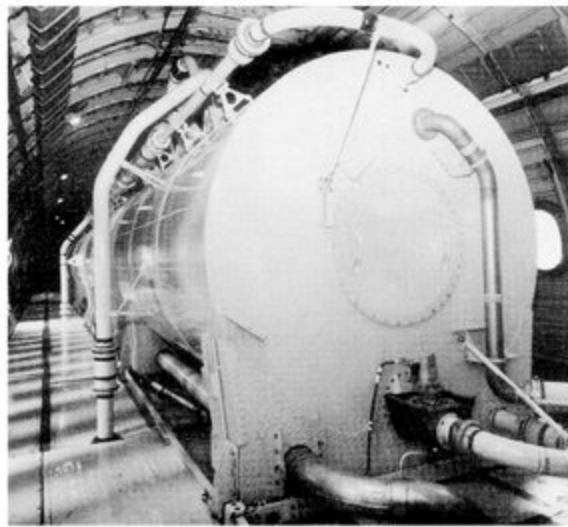
The aircraft's typical fuel system, shown in [Fig 297](#), incorporated the five new fuel cells shown below.

These were of double-skinned construction, with internal bags, or bladders, the inner skin being designed to support the bags or bladders, and the outer skin being designed to withstand the maximum cabin pressure differential of 9 lb per square inch.

The space between was vented to the atmosphere, thereby ensuring that no fuel vapour entered the cabin. The new cells were mounted on longitudinal floor beams, and were refuelled through a riser pipe in the main wheel bay, also being interconnected to a vent line that joined the centre-section transfer tank to the wing vent pipe. They were also interconnected by a fuel line to permit the fuel to be fed by gravity from the front cell to the rearmost cell, each cell having a flap valve at the base, thereby preventing a reverse flow occurring. The installation of the five cells in the four Mk 3s (Super VC 10) was simplified, as in the original design of the aircraft forward freight doors were incorporated through which the fuel cells could be loaded. However, in the five K Mk 2s (Standard VC10) they did not incorporate

the freight doors, and it was necessary to remove the fuselage roof to permit the cells to be installed. Fuel could be fed by gravity from either the rearmost or No. 3 cells via a fuel shut-off valve in two separate fuel pipes. The rear cell fed directly to the centre-section transfer tank, while the line from No. 3 cell fed the rear fuselage refuelling unit, and to the wing refuelling pods. The wing refuel/defuel line was originally the aircraft's fuel-jettison pipe, and due to its bore the required 350 imperial gallons (1,575 litres) per minute could not be achieved without a major modification. However, 275 imperial gallons (1,238 litres) could be achieved, which was acceptable, as not all combat aircraft could accept the fuel at the new high rate of flow. To meet this fuel flow, together with that required by the rear fuselage unit, an additional fuel pump was incorporated in each of the wing tanks, and two in the centre-section transfer tank, all of which were connected to the wing refuel/defuel gallery line via a shut-off valve.

Vickers VC10 tanker fuselage fuel cell



Of the three refuelling points fitted, the rear fuselage installation required the largest modification to the airframe.

This involved cutting into the pressurized structure aft of the main wheel bay, and ahead of the carry-on-through structure for the rear engine mountings, the refuelling unit being located at the same position relative to the rear of both types of aircraft, as shown below.



Vickers VC10 rear fuselage refuelling unit

This installation featured the Flight Refuelling Ltd Mk 17B refuelling package, which was similar to that installed in the Victor K Mk 2 tankers, and was capable of transferring 500 imperial gallons (2,250 litres) per minute with 50 psi (3.4 bar) at its reception coupling. The package occupied much of the original rear underfloor freight hold, and new pressure bulkheads were provided fore and aft of the required package cut-out, together with a pressure floor over the top with new side walls. The fuel line from No. 3 fuel cell, which supplied the refuelling unit in the rear fuselage, had a further shut-off valve incorporated; this permitted the removal of the refuelling unit with the minimum loss of fuel. A further fuel line incorporating a pressure-relief valve and a non-return valve was also connected to the rearmost fuel cell of the fuselage from the refuelling unit.

The large fixed scoop fairing on the underside of the fuselage provided the necessary ram air for the Mk XVIIB

hose-drum unit's fluid drive coupling's oil system and the cooling for the unit's drive motor. On the rear face and on either side of the fairing two sets of contact lights, Red, Amber and Green, were incorporated, and above the scoop exit and on either side were two floodlights to illuminate the underside of the aircraft for night operations.

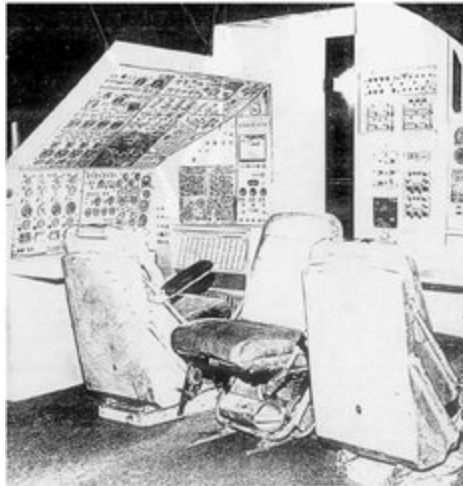
New structure was also incorporated between the wing spars to enable a refuelling pod to be carried beneath each wing on an under-wing pylon. The pylons were based on the design of the Victor K Mk 2 tanker type, and were permanently attached to the aircraft wings. They were located in such a position that they were clear of the aircraft's extensive trailing-edge flaps, and designed to be capable of carrying either the Mk 20B or the later Mk 32 Flight Refuelling Ltd air refuelling pods. The philosophy for the alternative design of refuelling pod was that at the time of the VC10 three-point tanker design study the Mk 32 refuelling pod was in the early stage of development, while the Mk 20B was a well-proved piece of equipment, the type having been used by both the Royal Air Force and the Royal Navy for a number of years. However, the Mk 32 refuelling pod was finally chosen, as it was of more modern design, less complicated using the fuel to power the hose-drum unit, and providing a higher rate of fuel flow. It is shown below.



Vickers VC10 wing Mk 32 refuelling pod

Although the two types of refuelling pod were considered, the earlier modification to the standard ARM E.8467 pylon sole-plate design introducing an additional fuel inlet forward of the suspension point was used similar to the Victor's. Pylon floodlights were fitted in both sides providing additional illumination of the underside of the aircraft's wing for night operations.

The control panels for the three refuelling units comprised two Mk XXXII and one Mk XVIIB panels, which were installed adjacent to the flight engineer's station on the flight deck, since he had control of the refuelling operation, as shown in the mock-up below. They were mounted on the starboard rear bulkhead of the flight deck, the two Mk XXXII panels being located above the Mk XVIIB.



Vickers VC10 flight engineer's station

To enhance the flight engineer's control; a closed-circuit television camera (CCT) was mounted in a small fairing externally beneath the aircraft's fuselage aft of the fuselage unit. The camera could be scanned to view each of the refuelling units, thus enabling the flight engineer to see the approach and contacts made by receiver aircraft. This was displayed on a small television monitor located above and to

the right of the Mk XVIIB control panel.

Prior to carrying out flight testing of the converted aircraft, a thorough ground functioning test was carried out to prove the fuel transfer and control system. To achieve this it was necessary to trail manually the refuelling hose, initially to the full-trail position of the unit under test.

Before carrying out the trailing sequence, the following selection on the unit's control panel had to be made. In the case of the Mk XVIIB, the master switch to 'ON', the fuel-valve switch to 'SHUT', fuel-pump switch to 'OFF', brake-reset switch to 'OFF' and the trail/wind switch to 'TRAIL', and the ground/flight switch on the unit's relay box to 'GROUND'. Once the hose was at the full-trail position, the trail/wind switch was selected to 'WIND', and the hose rewound to the required length to operate the fuel-valve switch, also confirming the contact lights sequence. In the case of the Mk XVIIB it was necessary to run the aircraft's engines, which supplied the air to the air-turbine fuel pump on the package. A standard ground discharge adaptor was engaged in the unit's reception coupling, which was connected by a further length of hose incorporating a fuel flowmeter, and thence to a ground refuelling bowser. When the aircraft engines had been started, the fuel-valve switch was selected to 'AUTO' and the fuel-pump switch to 'AUTO', the latter opening the air-gate valve and allowing the fuel pump to run. By varying the position of the fuel valve within the discharge adaptor, the fuel flow to the bowser could be reduced, causing the fuel pressure at the reception coupling to rise, and the pressure rise could be seen on the discharge adaptor's pressure gauge. The rise in pressure would therefore be sensed at the Mk XVIIB's fuel system venturi, which then signalled the fuel pump to reduce speed and thus the fuel flow, but maintaining 50 psi (3.4 bar) at the reception coupling. This type of testing simulated, by varying the fuel flow, the closure of a receiver aircraft's fuel inlet valves, whether it was ground or air refuelled.

Simulating a receiver aircraft making an emergency disconnect while the fuel was being transferred was achieved by fully opening the fuel valve in the discharge adaptor, then shutting it, so that the fuel flow to the bowser was stopped suddenly, causing a high transient fuel pressure at the reception coupling (surge pressure); again, this was sensed at the unit's venturi, which signalled the fuel pump to shut down.

On the completion of these tests a standard receiver aircraft was then coupled to the tanker and the tests were repeated.

The Mk XXXII refuelling pod, however, was powered by a ram air turbine that required a different technique from that of the Mk XVIIIB to drive its fuel pump to enable it to transfer fuel during ground testing. As it was the turbine's blade-pitch angle that controlled its speed and that of the fuel pump, the variation in blade-pitch angle was determined via the venturi within the pod's fuel system, either by an increase or decrease in fuel pressure at its throat. It was therefore necessary to simulate this method of control in the ground test drive unit, thereby enabling the pod to function in a similar manner to that when carrying out a normal refuelling operation.

To achieve this, it was necessary to remove the ram air turbine, as it was considered hazardous to have it rotating at a high speed during ground testing. It was therefore replaced by a dummy turbine having the blades removed, but providing the same weight and inertia characteristics as the standard turbine, together with the internal blade-operating mechanism. The dummy turbine was then connected to a hydraulic motor via a quill shaft, which was mounted in a truncated cone, which was in turn attached to the front of the pod once the fairings were removed, as shown below.



Mk XXXII refuelling pod test drive unit

The hydraulic motor's connections were connected to a hydraulic rig capable of supplying the necessary power, having an electrically operated flow-control valve incorporated in its supply line.



Mk XXXII test drive connected to hydraulic rig

To simulate the variation in the turbine's blade-pitch angle, a linear potentiometer was at one end attached to the front of the fuel pump's ball-screw mechanism (which operated the internal turbine's blade-pitch mechanism), the other to a fixed point on the fuel pump's casing. Thus, as the blade stepper motor on the pump was operated, moving the ball-screw in either direction (increase or decrease in fuel pressure at the throat of the venturi), the electrical output from the linear potentiometer signalled the hydraulic flow-control valve to either increase or decrease the hydraulic oil flow to the driving motor, so increasing or decreasing its

speed, and thus the fuel flow from the pump.

The ground testing of the wing pod was carried out in a similar manner to that of the Mk XVIIB unit, the refuelling hose having to be manually trailed, but the method of carrying out this differed slightly as the pod's fuel/hydraulic system had to be used to enable the hose drum's brake to move to the 'OFF' position.

To achieve this, it was first essential to attach the hose drum's ground winding handle to the drive gearbox. This was necessary, as when the hose was manually wound off the drum the Tensator spring motor would automatically rewind it, as there was no drogue drag load.

Prior to actually manually winding the hose to the full trail position, the hydraulic ground test rig was operated to supply the power to the hydraulic motor located on the truncated cone. Owing to the setting of the linear potentiometer, sufficient power was applied to drive the dummy turbine at its normal idling speed. By selecting the master switch on the pod's control panel to 'ON', and the Trail/Wind switch to 'TRAIL' the RED contact light was illuminated, the hose-drum control valve initially moving to the 'WIND' position. This supplied sufficient power to the vane/motor pump to rotate the hose drum in the wind direction, automatically moving the hose-drum brake to the 'OFF' position. Immediately the brake was fully 'OFF', it signalled the hose-drum control valve to move to the 'Trail' position, thus allowing the drogue and reception coupling to be ejected via its buffer spring. The hose could now be manually wound out to the fully trailed position, and in doing so it extinguished the RED contact light, illuminating the AMBER, the brake being automatically applied to 'ON'. Having got the hose to full trail, it was now possible to rewind it with the assistance of the Tensator spring motor via the ground winding handle. It was rewound until the fuel/vent valve was opened respectively, automatically extinguishing the AMBER contact light and illuminating the

GREEN, the hose at this position being held by the mechanical brake within the winding handle. Similar to the Mk XVIIB, the ground discharge adaptor was engaged in the reception coupling in readiness to transfer the fuel to the ground refuelling bowser. With the shut-off valve in the adaptor closed, the venturi sensing that there was no fuel pressure, the turbine pitch stepper motor on the fuel pump operated, thus moving the linear potentiometer demanding an increase of speed via the hydraulic flow-control valve to the hydraulic motor.

When 50 psi (3.4 bar) was sensed at the reception coupling via the venturi, the speed was automatically controlled to maintain this pressure with no flow. On opening the shut-off valve in the adaptor, the pressure at the reception coupling and venturi would initially decrease, thus demanding more speed to maintain the 50 psi (3.4 bar) and a fuel flow. The latter depended on how much the shut-off valve was opened. Once this ground test had been satisfactorily completed, as previously stated the tanker aircraft was connected to a receiver aircraft.

The prototype VC10 K Mk 2 three-point tanker ZA.141 made its maiden flight on 22 June 1982, which was an initial handling flight to determine if there were any problems caused by the addition of the in-flight-refuelling installations. However, during the early flight testing problems did arise with the wing pylon's electrical butt connectors to the Mk XXXII refuelling pod.

The connectors, however, were identical to those used on all of the Mk XX series of refuelling pods, although intermittent problems had occurred. The problem with this installation was that during flight the connectors became intermittently separated between the pylon sole-plate and the pod, thereby braking the electrical supplies to the pod. It upset the pod's electronic logic system, causing the pod not to respond correctly to the operational sequences selected by the operator, such as the hose trailing when 'wind' was

selected. During the debriefing of this particular flight the following comment was made: 'The pod has a mind of its own, doing whatever it wants to do regardless.' Nevertheless, the problem was soon overcome by the deletion of the butt connectors and replacing them with plugs and sockets on flying leads, and no further problems were incurred thereafter.

During further flight trials a landing was made with the hose on the starboard wing pod trailed. On all previous hose-drum units when carrying out this procedure the hose would remain at the full trail. However, the Mk XXXII pod incorporated a Tensator spring motor that would automatically rewind the hose once the drogue drag and hose trailing weight were reduced.



Vickers VC10 K Mk 2 trailing Mk XXXII pod hose

The following photographic sequences, shows the aircraft flying overhead with the hose fully trailed, then the aircraft touched down with the hose and drogue landed on the runway, but as its speed decreased the hose automatically wound in via the power supplied by the Tensator spring motor thereby



VC10 K Mk 2 landing with wing pod hose trailed

keeping the drogue and reception coupling airborne. On inspection after the landing event, it was found that the equipment had suffered minimal damage, enabling it to be reused.



VC10 K Mk 2 hose rewind on landing

The prototype flight trials, which included those of the parent company and A&AEE Boscombe Down, continued through 1982 until mid-1983, when Boscombe Down gave the necessary clearance for service use. On 25 July 1983, at the handing-over ceremony at Filton, Air Chief Marshal Sir David Craig (later to become chief of the defence staff during the Gulf War) accepted the first production VC10 K Mk 2 ZA.140 for the Royal Air Force, and after the ceremony it flew to RAF Brize Norton to commence operations with 101 Squadron.

CHAPTER THIRTY-ONE

Mk 35/2800

Refuelling Pod

The Grumman Aerospace Corporation submitted an unsolicited proposal to provide the US Navy with a reliable replacement for the currently used air refuelling store. The proposed design, currently designated Mk 35/2800 aerial refuelling store, was based on the Royal Air Force's service-tested aerial refuelling system, designed, produced and continuously developed by Flight Refuelling Ltd (FRL) of Wimborne, Dorset, England. Grumman and FRL had agreed to combine the necessary talent and resources to integrate Grumman's structural design, structural test and flight-test capability with FRL's proved system components. As the prime contractor, Grumman was fully responsible for the proposed programme, and would provide the aircraft interface and structural support for the proved aerial refuelling system to be provided by FRL.

The proposal presented the technical, programming and managerial considerations to provide refuelling stores for carrier-based naval evaluation in mid-1983.

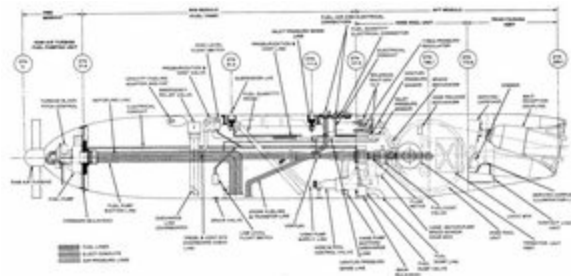
The Mk 35/2800 air refuelling store had been configured to exceed the capability of the existing US naval air refuelling store. Briefly the proposed Mk 35/2800 had the following:

300 US gallons of internal fuel

- 420 US gallons per minute maximum transfer rate
- Automatic deliverable quantity scheduling of fuel transfer
- Built-in test equipment
- High reliability
- Mechanical interface compatible with existing US Navy aircraft

A major objective of the proposal was to design and to ensure that the store envelope was compatible with the existing American D.704 store. This was required to ensure that the proposed pod could be used with no structural modifications to tanker aircraft in any location where the existing D.704 store was used.

The refuelling store was divided into three modules: the forward module containing the ram air turbine and fuel pump that formed the power unit was the responsibility of FRL; the centre module, containing the fuel tank and hardback was the responsibility of Grumman Aerospace, and the aft module containing the hose-drum unit and control components was also the responsibility of FRL. The complete assembly is shown in [Fig 299](#).

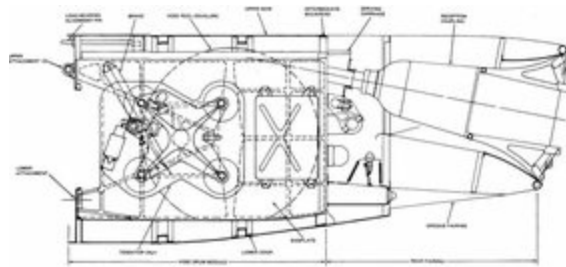


[Fig. 299](#). Grumman/FRL Mk 35/2800 refuelling pod

The complete assembly was designed to be in three

removable modules and tested as individual assemblies. The forward-module power unit containing the ram air turbine and fuel pump was identical to that of the Mk 32/2800 refuelling pod. Likewise, the aft module containing the hose-drum unit was basically also identical, containing the refuelling hose, reception coupling and the control units, but tailored to suit the new pod envelope, as shown in [Fig 300](#).

[Fig. 300](#). Mk 35/2800 refuelling pod aft module



It was therefore only the centre module, the fuel-tank, that would be the really new component, which included a completely new centre-module structure, together with American fuel system components other than those that operated in conjunction with the power unit and hose drum.

The centre-module structure, shown in [Fig 301](#), was to be designed and manufactured by Grumman Aerospace at Bethpage, Long Island.

The ram air turbine/fuel pump unit was cantilevered from the tank's front pressure bulkhead and was enclosed by separate fairings. The centre-module fuel-tank was of a monocoque structure, having a forward and aft pressure bulkhead with two substantial frames located adjacent to the two pod suspension hooks. The two frames were attached at the top of the module by a machined hardback that incorporated the necessary aircraft interfaces and Aero 7B rack hook and swaybrace interface. The hardback was capable of accepting all of the loads that interfaced with the

pod through the suspension rack, which was mounted to the aircraft. Grumman experience of the Aero 7B rack was considered, whereupon the following ground rules and assumptions were mandated for the preliminary design:

Swaybraces took the compression loads onto the tank's surface

Hooks took the loads in all directions

Fore and aft loads were taken in the most critical manner, i.e. all load at forward hook or the aft hook

The complete tank was skinned and extended beyond the rear bulkhead to a further intermediate frame forming the hose-drum-unit bay. The bay had side and bottom access doors that provided the necessary access to the hose-drum-unit components; the intermediate frame also had the hose serving carriage mounted to it and driven by the hose drum.

Beyond the intermediate frame was the rear removable fairing, this being attached to the frame with quick-release fasteners. This contained the drogue stowage tunnel and contact lights, similar to the Mk 32/2800 refuelling pod.

The fuel system, both for powering the hose drum and for the fuel transfer, which is shown in [Fig 302](#), consisted mainly of American fuel system components, but used British where the component was a part of the hose-drum and fuel-transfer-system control.

Because the overall fueldraulic system was now within a fuel-tank, the closed-loop system was no longer required, as the exhausted fuel from the hose-drum driving motor could now be returned to the tank; therefore the motor could have an exhaust pipe in the winding sequence, and return the fuel to the tank in the trail sequence via the hose-drum control-

valve port, the exhaust pipe in this mode becoming a suction pipe. Thus the British components within the fuel-tank were the hose-drum control valve, two pressure sensors and the fuel pump. The remainder were of American origin, such as a pressurization and vent valve, emergency pressure-relief valve, high-level float-switch, fuel-quantity probe, drain valve, low-level float-switch and all components that were necessary for the fuel-tank to operate as a drop-tank.

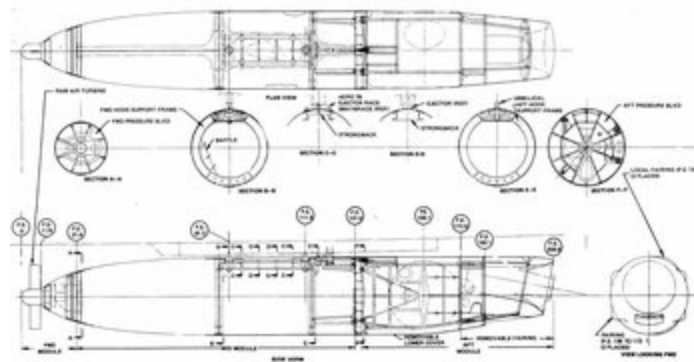


Fig. 301. Mk 35/2800 refuelling pod structure

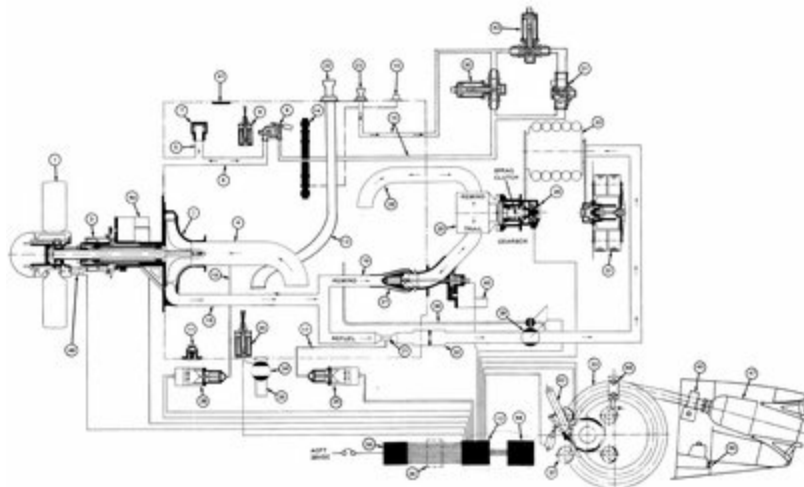


Fig. 302. Mk 35/2800 refuelling pod diagram of system

The control panel was to be designed by Grumman Aerospace, thereby making it compatible with existing naval

aircraft cockpits.

Weights and Dimensions

Dry weight estimated:	942 lb
Wet weight estimated:	2,982 lb
Capacity of fuel-tank:	300 US gallons
Diameter of pod:	30.25 inches
Overall length of pod:	208.30 inches
Diameter of turbine blades:	25.00 inches
Refuelling hose:	2.00-inch bore x 2.65-inch o/d x 52 feet
Diameter of drogue deployed:	24.00 inches
Reception coupling:	MA-3

Operator's control panel (prototype flight test only)

Maximum width	6.60 inches
Maximum height	7.00 inches
Maximum depth from rear mounting face	3.00 inches
Length of electrical loom to rear of sockets	24.00 inches

Fixing centres width	6.10 inches
Fixing centres height	6.30 inches
Weight of panel	5.20 lb

Performance

Delivery rate	420 US gallons per minute
Reception coupling pressure	50 psig
Altitude	0-40,000 ft

Characteristics

Speed of 25-inch diameter two-bladed featherable turbine

Feathered (prototype only)	1,000 rpm
Normal	6,900 rpm
Overspeed	7,200 rpm

Hose 'Wind' and 'Trail' speeds, hose on bottom

layer

Wind	2.0 ft/sec
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Trail	4.0 ft/sec
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Hose drum take-up (response)	12-knot receiver overtaking speed
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Electrical Supplies

Service	28 V DC
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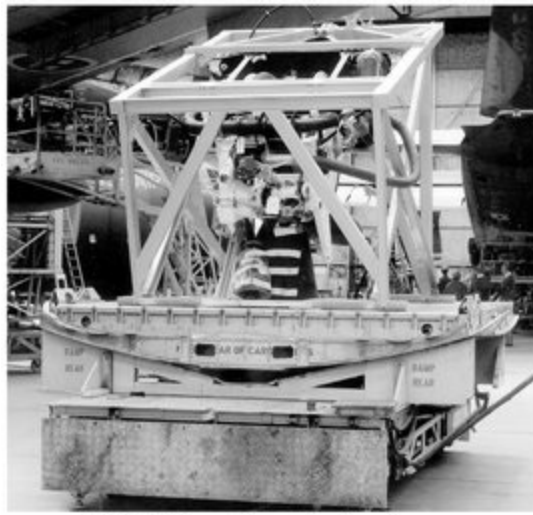
Maximum current	18 A
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CHAPTER THIRTY-TWO

Lockheed C-130

Hercules Tanker

The first Mk 17B refuelling package for the prototype Hercules single-point tanker was delivered to Marshalls of Cambridge on 1 May 1982. The package was mounted to the rear lower cargo ramp within a rectangular support structure, it being sufficiently stiffened to absorb the applied hose-drum-unit loads, as shown below.



Mk 17B refuelling package on Hercules tanker cargo ramp

The assembly to the cargo ramp was completed by 15 May 1982. The drogue stowage tunnel was secured to the upper cargo door, with the contact lights (Red, Amber, Green), two sets of which were mounted on either side of the tunnel, as

shown below.



Hercules tanker drogue tunnel and contact lights

It was positioned to permit the refuelling hose to trail through it at the various trailing angles, and incorporated a secondary serving carriage, which was not mechanically driven, but slid on its own support tubes by the sideways action of the refuelling hose, as shown below.



Hercules tanker, refuelling hose trailing

The fuel, air and cooling ram air systems are shown diagrammatically in [Fig 303](#), in which the fuel supply to the refuelling package fuel pump was taken from the main aircraft fuel gallery in its dry bay. Two fuel pipes were connected to the normal refuel/defuel pipe, and ran aft through two electrically operated fuel shut-off valves, through the centre cargo bay, along the roof, to two manually operated shut-off valves. These two valves were

the means whereby the fuel supply could be closed off, permitting the refuelling package to be removed from the aircraft without any spillage of fuel. These valves were connected to the refuelling package's two fuel inlets by flexible hoses, and transfer of the fuel to the package's system was achieved through the aircraft's dump valves and dump pumps; during the transfer, dump valves 'X' port and starboard remained shut.

Fuel entered the refuelling package's system via a pressure-relief valve that at times could relieve a large quantity of fuel. The relieved fuel was piped along the centre cargo bay, the pipe running below the two fuel supply lines, and then out through the starboard wing's rear beam to No. 3 fuel-tank. Two fuel-check valves were incorporated in the pipe to prevent a reverse fuel flow occurring from the fuel-tank.

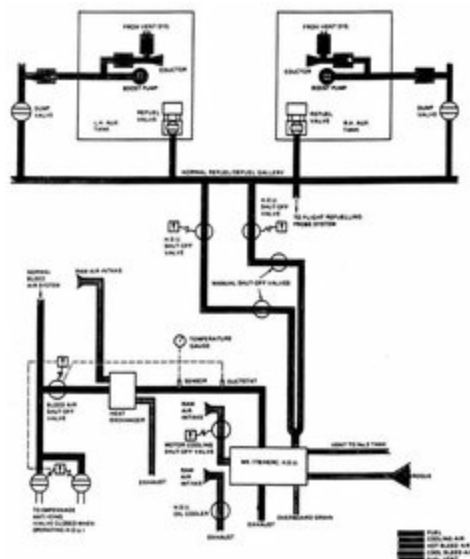


Fig. 303. Hercules tanker fuel and air systems

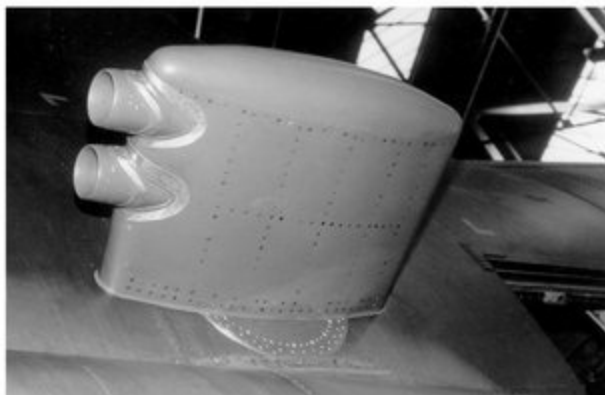
Fuel transferred to a receiver aircraft was pumped from the refuelling package's air turbine fuel pump; the fuel system of which incorporated a shock alleviator to prevent high-fuel-

pressure surges affecting the aircraft's fuel system when a receiver aircraft's fuel-tank valves closed. The fuel flow and quantity of fuel transferred were both indicated in pounds on the package's control panel.

To compensate for thermal expansion of fuel within the transfer system, and over-pressurization, a small vent line was connected to the package's vent; this incorporated a check valve and pressure-reducing valve, which in turn was connected to No. 3 fuel-tank.

The air supply to power the refuelling package's air turbine fuel pump was taken from the normal bleed-air system that fed the aircraft's empennage anti-icing system. A pipe teed into this system was led through a shut-off valve, and thence through a heat exchanger to the shut-off valve at the air turbine's inlet. As the turbine of the fuel pump was limited to a maximum of 250 °C, this reduced the supply-air temperature to an acceptable level, this being achieved by ram air being passed through the exchanger acting as a coolant, and after passing through it being exhausted to the atmosphere. Between the heat exchanger and the air turbine fuel pump's shut-off valve two tappings were incorporated—one for a temperature gauge providing visual indication of the air temperature, and the second for a Ducstat that was connected to the two shut-off valves controlling the empennage deicing. During the operation of the air turbine pump these two valves were in the closed position.

Two further ram air cooling intakes were required for the refuelling package—one for the package's hose-drum drive motor, the other for the hose-drum unit's fluid drive coupling's oil system. The drive motor's ram air cooling pipe incorporated an electrically operated shut-off valve, while the oil-cooling pipe had a manually operated shut-off valve. All the ram air cooling ducts protruded externally of the fuselage; one being on the port side, and the other two on the starboard, as shown typically below.



C-130 Hercules tanker, typical ram air intake

The aircraft had floodlighting incorporated to illuminate the under-wing surfaces, and the lower rear ramp area for night operations.

Three new control panels were introduced to operate the air refuelling system through their switches and indicators. These were a standard Mk 17B air refuelling package control panel, a hose drum auxiliary panel and a flight refuelling panel. All of these were located at the navigator's position on the flight deck. The photograph shows the two former panels located above one another, and the flight refuelling panel above and to the right.

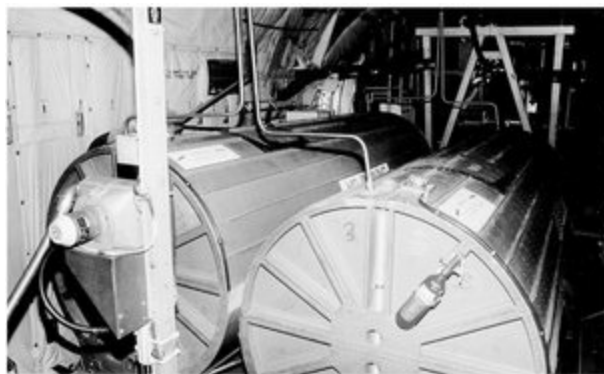


C-130 Hercules tanker air-refuelling control panels

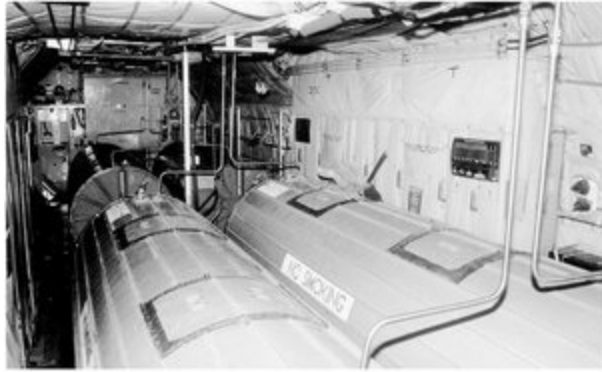
The navigator had control of the refuelling operation. The panels controlling each of the operating systems are tabulated below:

1. The standard Mk 17B control panel controlled the operation of the refuelling package's hose-drum unit, contact lights, fuel-pressure indicator, hose-release jettison mechanism and fuel-pumping system.
2. The hose-drum auxiliary panel controlled the operation of the ram air bleed valves, floodlighting controls, rate-of-fuel-transfer indication and aircraft fuel shut-off valves.
3. The flight refuelling panel repeated the ground/defuel panel, and controlled the aircraft's probe lighting, panel lighting, the fuselage tank's contents gauges, fuel-pump switches, and the fuselage tank's low-pressure warning lights.

To augment the aircraft's transferable fuel, four auxiliary fuel-tanks were installed within the aircraft's freight hold, as shown below. These provided a further 2,800 lb (350 imperial gallons, or 15,750 litres) of transferable fuel.



Auxiliary fuel-tanks, Hercules tanker, looking aft



Auxiliary fuel-tanks, Hercules tanker, looking forward

To enable a quick installation to be carried out; existing Andover aircraft ferrying tanks were employed, the installation of which was carried out through a Service Engineering Modification numbered SEM/Herc/074/STC. All six tanker conversions, i.e. XV.201, XV.203, XV.204, XV.213, XV. 192, and XV.296, had this modification incorporated through Squadron Engineering.

The complete auxiliary tank system is shown diagrammatically in [Fig 304](#). It comprised the four Andover aircraft ferrying tanks, and a fuel collector box containing three fuel pumps was connected to the auxiliary fuel-tanks by four separate fuel pipes. The fuel outlet of this was routed via a flexible hose to the front beam of the wings' centre dry bay. In turn this was connected to an existing port in the three-way casting that joined the fuel manifold to the single-point ground refuelling connector within the aircraft's starboard undercarriage bay. A further fuel pump was connected to one of the auxiliary fuel-tanks by a 'Wanderlead' to enable the fuel to be drained from the tanks in the event of a malfunction of the pumps within the collector box. This was connected to the outlet pipe of the collector box, having a non-return valve fitted, and a similar valve was incorporated in the pump's outlet pipe.

with surge-pressure checks

Monday 7 June	Preparation for flight test: aircraft pressurization check
Tuesday 8 June	Initial flight test: aircraft unpressurized; drogue successfully deployed
Thursday 10 June	Test flight: aircraft pressurized; drogue successfully deployed
Friday 11 June	Aircraft delivered to A&AEE Boscombe Down
Saturday 12 June	Boscombe Down handling flight: some elevator buffet and slight increase in stick forces reported. Decision to tuft aft fuselage
Sunday 13 June	Further handling flight: dry contact with Harrier
Monday 14 June	and Hercules receivers. Problems experienced with hose-drum wind-in, and overheating of hose drum's oil-cooling system. Hose-drum unit serviced and some components changed. Decision to return aircraft to Cambridge
Wednesday 16 June	Separate air intake fitted to port side of aircraft,
Saturday 19 June	and drag reduction programme undertaken, culminating in fitting strakes to cargo door
Sunday 20 June	Test flight with additional strakes: buffet cleared, and hose-drum-unit cooling

system satisfactory. Decision taken on prototype and subsequent aircraft that a dry and wet contact be achieved before delivery

Monday 21
June

Test flight: successful deployment of drogue and wet transfer with Buccaneer receiver 5,000 lb of fuel transferred at 1,000 lb per minute, using dump pumps only

Tuesday 22
June

Aircraft delivered to A&AEE Boscombe Down

Wednesday 23
June

Weather not acceptable for trial flight; hose-drum-unit pressure-reducing valve sent to Plessey Ltd for servicing

Thursday 24
June

Handling flight trials, buffet problem cleared. At 30,000 feet maximum differential pressure some problems reported. Drogue successfully deployed wet transfer using dump pumps only

Friday 25 June

Complete check of hose-drum-unit system by Flight Refuelling Ltd; reset pressure-reducing valve fitted. Test flight: hose trail wind-in satisfactory. Some problems still experienced with hose-drum air-turbine fuel pump

Saturday 26
June

Air-turbine fuel-pump gate-valve problem identified, and aircraft blanking plug reduced in length

CHAPTER THIRTY-THREE

Lockheed C-130

Hercules C Mk 1 Receiver

On 15 April 1982, Marshalls of Cambridge was requested by the Ministry of Defence to design, install and flight test an air refuelling probe on the Lockheed C-130 Hercules C Mk 1 aircraft of the Royal Air Force. This would then enable the Hercules to carry out supply drops to the forces en route to the Falkland Islands, and provide the necessary support to the land forces once they had landed.

Instructions to proceed were given in the afternoon of 15 April, the design of the installation commencing during the night of the same day, and the installation being started on the following day, 16 April. The aircraft for the prototype installation, XV.200, had been delivered to Marshalls on the same day as the instructions to proceed, thus showing the urgency of the requirement.

No precedent was in existence for this type of installation at the time, other than a small number of American aircraft, which had under-wing probes fitted. Working round the clock, the first aircraft (XV.200) had its probe installation, together with the necessary fuel piping, completed within the space of two weeks, this being on 25 April 1982.

The probe assembly comprised a ready-made basic probe tube taken from the Avro Vulcan receiver aircraft that were no longer in service use, and attached to it was a Flight Refuelling Ltd Mk 8 probe nozzle, together with a fuel line located beneath a fairing. The complete assembly was

secured to the upper surface of the forward fuselage externally (Fig 305), and offset to the starboard side.

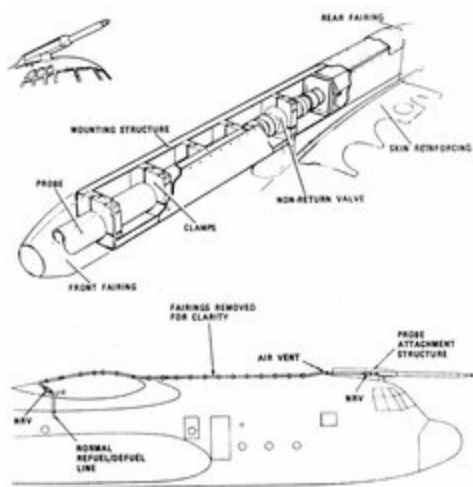


Fig. 305. Lockheed C-130 Hercules C Mk 1 receiver probe

The fuel line from the probe nozzle to the aircraft's fuel system ran along the top of the fuselage beneath the fairing, and entered the wing's trailing-edge fillet to connect with the existing vertical ground refuelling line on the fuselage's starboard side. Having the refuelling line from the probe mounted externally beneath its fairing prevented any disturbance of the aircraft's pressurization system, and was of a simple design. Behind the probe nozzle a non-return valve was incorporated within the fuel line to ensure that there was no fuel spillage in the event of the aircraft losing the probe nozzle via its weak link or a malfunction. Two floodlights were located within the cockpit forward of the second pilot's position, and the beams of these were directed through the windscreen to illuminate the probe nozzle during night contacts.

As previously stated, the first installation was completed on 25 April 1982, and is shown below. This was followed by ground testing of the system on 26 April. The first handling flight to prove that there were no performance problems was

carried out from Cambridge on 28 April 1982. The aircraft was then flown to A&AEE Boscombe Down for final approval of the installation, further ground testing and flight testing.

Lockheed C-130 Hercules receiver probe



The ground testing by the staff of A&AEE commenced on 1 May 1982, when Hercules XV.200 was coupled to a Victor K Mk 2 tanker to confirm the fuel flow characteristics, and fuel pressures derived from fuel-tank valve closures during the fuel transfer. After successful completion of the ground testing, XV.200 made its first wet airborne contact on 2 May 1982, and this was followed by further flight tests making successful wet contacts, during which one was made at night. The events described showed that the design, installation and initial testing totalled fifteen days, and the formal approval and further flight testing by A&AEE took a further six days, making the overall time for the conversion to a receiver just twenty-one days, which was a record achievement by all those involved. Further contacts at a later date were made with the new VC10 K Mk 1 tanker, as shown in the photograph and viewed from adjacent to the Hercules probe.

The first long-range operational air refuelled flight by a Hercules of the Royal Air Force was made by Flight Lieutenant Harold Burgoyne of No. 47 Squadron on 16 May

1982, making a journey from



Hercules in contact with VC10 K Mk 1 tanker

Ascension Island to the Falklands 'Total Exclusion' zone, and covering 7,247 miles in 24 hours 5 minutes. Long-range support continued to be made by both 47 and 70 Squadrons throughout Operation Corporate.

Further conversions were carried out to provide the Hercules with the capability of being air refuelled, and some of these are tabulated below with their installation and delivery dates.

Aircraft	Date Installation Commenced	Delivery date	Remarks
XV.179	26 April	13 May	Included a major inspection flight
XV.218	14 May	25 May	
XV 196	17 May	31 May	
XV 206	21 May	3 June	
XV.291	25 May	6 June	Aircraft retained at Cambridge for a ground transfer of fuel from the first Hercules tanker
XV.210	14 June	29 June	
XV.211	21 June	6 July	
XV.296	1 May	11 June	Also became the first Hercules tanker
XV.201	25 May	15 July	Also became the second Hercules tanker
XV.204	12 June	21 July	Also became the third Hercules tanker
XV.192	21 June	26 July	Also became the fourth Hercules tanker

CHAPTER THIRTY-FOUR

Shin Meiwa US-1

Tanker/Receiver

The Japanese Navy requested Flight Refuelling Ltd to propose a method of air refuelling the Shin Meiwa US-1 flying-boat to be to be refuelled in flight, and refuel a receiver aircraft through the same system. The latter method of refuelling could make use of the vice versa system conceived in 1966, thus enabling the tanker to refuel another flying-boat that had made an emergency landing on water.

However, to evaluate a system for this type of operation, it was first necessary to study the aircraft's fuel system, to find what was required to be incorporated to achieve a satisfactory system for the two types of operation. It was found that two new transfer fuel pumps would be required, one for the transfer during the standard method of probe and drogue air refuelling, together with a venturi and fuel-pressure sensors, the second with similar equipment for the vice versa system, and in addition a series of fuel shut-off valves to enable the operator to select either system. To complete this phase of the study three systems diagrams were drawn (illustrated in [Figs 306, 307 and 308](#)).

The first shows the system selected for the standard receiver role, and the following list indicates the total system equipment requirement, suitably numbered to identify the components.

4. Fuel-tank engine pump
5. Fuel transfer pump

6. Fuel-tank filter
7. Fuel jettison pump
8. Ground manual fuel shut-off valve
9. Ground refuelling coupling
10. Ground refuelling coupling
12. Non-return valve
14. Non-return valve
15. Fuel-tank contents gauge
16. Fuel-tank contents gauge
17. Fuel-tank contents gauge
20. Fuel-tank contents gauge
24. Fuel shut-off valve, vice versa air refuelling/engines
25. Fuel-tank inlet shut-off valve
26. Fuel shut-off valve, vice versa air refuelling/engines
27. Fuel shut-off valve, vice versa air refuelling/engines
28. Fuel-tank inlet shut-off valve
29. Fuel shut-off valve, vice versa air refuelling/internal transfer
30. Fuel shut-off valve, internal transfer/engines
31. Fuel shut-off valve, internal transfer/engines
32. Fuel shut-off valve, internal transfer/engines
34. Fuel shut-off valve, internal transfer/engines
38. Fuel shut-off valve, air refuelling
39. Fuel-tank vent valve
40. Fuel-tank vent valve
41. Fuel line shut-off valve
42. Fuel line shut-off valve
45. Fuel jettison shut-off valve
46. Non-return valve
47. Fuel shut-off valve
50. Fuel-surge alleviator, vice versa air refuelling
51. Fuel-pressure sensor, vice versa air refuelling
52. Venturi, vice-versa air refuelling
53. Fuel transfer pump, vice versa air refuelling
54. Fuel shut-off valve, receiver air refuelling
55. Fuel shut-off valve, fuel vent line
56. Fuel shut-off valve, receiver air refuelling

- 57. Fuel-pressure sensor switch, vice versa air refuelling
- 58. Fuel transfer pump, air refuelling
- 59. Fuel vent box
- 60. Fuel vent shut-off valve
- 61. Non-return valve
- 62. Fuel-pressure sensor, air refuelling
- 63. Venturi, air refuelling
- 64. Fuel flow transmitter
- 65. Fuel shut-off valve, vice versa air refuelling
- 66. Fuel shut-off valve, vice versa air refuelling.

As mentioned above, the first figure illustrates the aircraft's system in the standard receiver role.

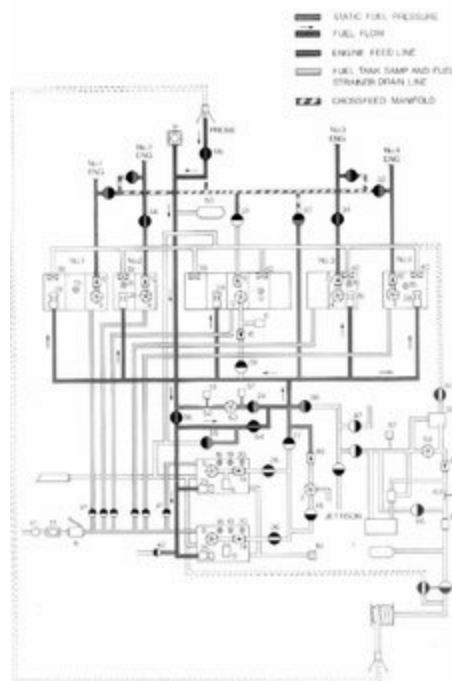


Fig. 306. Aircraft system in receiver role

Fig 307. shows the receiver aircraft's system in the tanker role using the vice-versa method of transferring the fuel to another aircraft via the aircraft's refuelling probe.

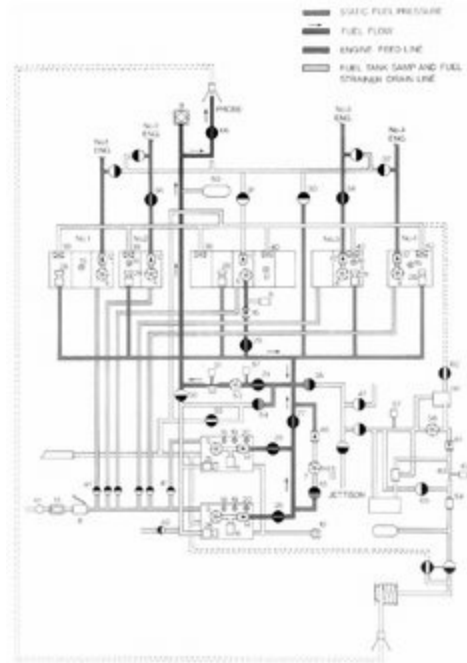


Fig 307. Receiver aircraft in tanker role

Similarly, in [Fig 307](#), the tanker aircraft is in the receiver role, using the vice versa system through its own hose-drum unit to refuel all aircraft fuel-tanks.

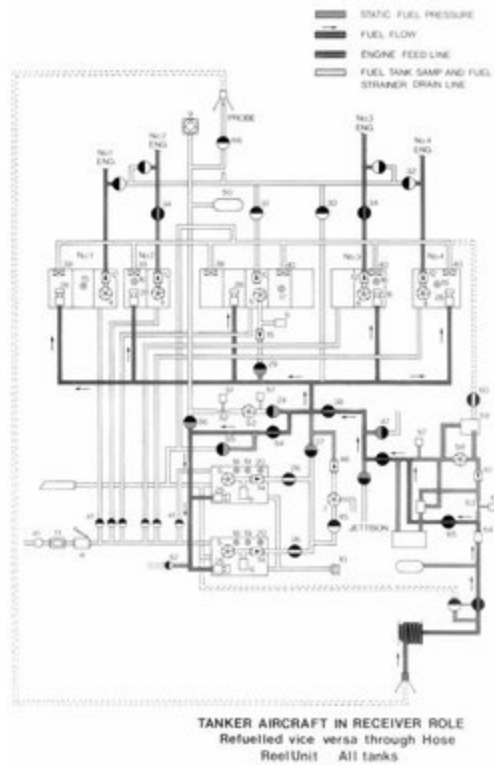


Fig. 308. Tanker aircraft in receiver role

To convert the aircraft for the vice versa method of refuelling, and its own receiver role, the fuel system was modified by the installation of the receiving probe and fuel shut-off valves, a new transfer pump with the pressure-sensing venturi and its pressure sensor and pressure-switch, which would operate in a similar manner to that of the standard air refuelling system, and a fuel-shock alleviator adjacent to the probe to absorb high-fuel-pressure surges when the fuel valve within the probe closed during an emergency disconnect.

The refuelling probe was to be of a retractable type (Fig 309), and comprised the following:

The probe

The deployment mechanism

The probe support, to be designed by either Flight Refuelling Ltd or the parent aircraft company.



Fig. 309. Shin Meiwa retractable refuelling probe

The deployment, retraction and locking were a hydromechanical function utilizing the aircraft's hydraulic system, and were controlled by the aircraft's pilot. Three electrical switches provided signals to the pilot: one was connected the circuit that indicated that the probe assembly was deployed, a second that the probe was retracted and locked, and the third connected the circuit that indicated the pressure of fuel being supplied by the tanker aircraft.

The probe assembly incorporated a telescopic tube assembly with a Mk 8 probe nozzle secured at one end and a probe joint coupling at the other. The probe tube assembly had two light-alloy tubes, one sliding within the other. The inner had a bearing holder secured to one extremity by a trapwire, the holder retaining two PTFE bearings that freely located against the internal surface of the outer tube. A seal housing carrying two O-rings and a special ring were retained and secured by a scraper ring to the outer tube. The O-rings reacted against the inner surface of the outer tube and the special seal reacted against the outer surface of the inner tube, thus providing a seal over the telescoping

actions.

An angled adaptor for the attachment of the nozzle was riveted to the end of the outer tube, and a link pivot and lock-catch assembly was secured by two stops and four keys midway along its length.

The probe joint coupling had a spherical end-fitting, a non-return valve, an inward vent valve and a pressure-switch locating position. The spherical housing, which was the main body of the coupling assembly, had two large apertures: in one was fitted the non-return valve, and in the other the spherical end-fitting, and the inward vent valve was screwed into a smaller aperture in the housing wall. The spherical end-fitting rotated in two spherical bearings that were separated by an O-ring housing. A waved spring-washer and thrust-washers maintained the spherical bearings in contact with the end-fitting, and the complete assembly was retained together by a housing cap that was bolted in position. Thus the spherical fitting was sealed throughout its full range of movement. Two further O-rings sealed the assembly of the spherical end-housing cap and the spherical housing, and a rubber gaiter fitted over the joint to provide a protective cover.

The non-return valve was a spool type of valve, composed of a cylindrical body with an integral web in which slid a valve head. The valve head abutted the end-face of the body and was held in the closed position by a compression spring. The body of the non-return valve was secured to the spherical housing by a retaining ring and sealed by an O-ring. The inward vent valve was also a spool-type valve, embodying a spring-loaded spindle and seal that were held in the closed position similarly by a compression spring. A bonding wire assembly was fitted between the spherical housing and the end-fitting.

The probe deployment mechanism had a hydraulic actuator that was connected to a box-section link assembly.

The link was connected, on assembly, to the link pivot and lock-catch of the probe assembly, and also to the in-flight-refuelling support beam via close-tolerance shafts also bonded to the aircraft structure.

The actuator was a double-acting unit with a steel cylinder and multi-part removable trunnion, which was located in the support beam.

The piston rod operated through a sealed end-cap that was screwed into the cylinder, which also housed a scraper ring. A spherical bearing in the piston-rod eye-bolt provided an attachment for the link assembly using a close-tolerance shaft.

Dynatube standard elbow connectors were provided for the coupling of the support-beam-mounted flexible hoses. The 'extend' elbow was secured by a clip assembly on the cylinder and connected to a pipe sub-assembly.

An end-fitting was screwed onto the open end of the cylinder and locked by a nut and key. A signalling switch was screwed into the end-fitting, which also housed a switch-actuating lever and shaft assembly and received the spigot connector of the hydraulic-pipe sub-assembly.

The internal locking mechanism, which secured the piston rod in the closed position, consisted of six bevelled segments that engaged in the slots in the head of the rod and were held in the outer locked position by a spring-loaded piston. Hydraulic pressure to extend the main piston rod moved the lock piston clear of the segments, which then moved radially into the unlocked position, allowing the piston rod to extend.

In the closed and locked position the lock piston actuated the lever shaft, which depressed the plunger of the signalling switch.

The down-latch mechanism comprised a hydraulic actuator mounted on a lock housing, which in turn was secured to the in-flight-refuelling support beam. A lock-latch was connected

to the actuator piston rod, and this latch was designed to engage with the link pivot and lock-latch on the probe assembly. An electrical switch was mounted on the lock-catch to provide an electrical signal when the probe assembly was retracted and locked down.

The down-latch actuator unit was a double-acting actuator comprising a steel body and piston, which operated through an aluminium-alloy gland. Seal assemblies were fitted to the body, the gland and piston. The body was drilled for fluid passages and tapped for two Dynatube standard adaptors that provided for the coupling of the support-beam-mounted flexible hoses, each adaptor being sealed by an O-ring packing.

The gland was screwed into the body and was fitted with a piston scraper ring assembly retained by a spring-ring. Four lugs on the body were drilled for mounting the actuator, and the outer end of the piston rod was also drilled for attachment purposes.

Principle of operation

DEPLOYMENT

*Note:*When the probe was in the stowed position there was no hydraulic pressure acting on the actuators.

When the probe assembly was selected to the deployed position, hydraulic pressure was first applied to the down-latch actuator and thence to the probe-deployment actuator, the timing being controlled by the hydraulic system components (this being the aircraft manufacturer's responsibility). When the down-latch piston moved, the locking latch would be pulled clear of the link pivot and lock-catch on the probe assembly, and simultaneously the lock-latch electrical switch would be operated to provide the appropriate aircraft signal.

Subsequent hydraulic pressure to the deployment actuator

caused the actuator to retract and move the probe assembly to the deployed position. At maximum travel the mechanical locks within the actuator engaged and simultaneously operated the inbuilt electrical switch to provide the appropriate aircraft signal.

*Note:*The hydraulic pressure was supplied to the jack during the whole period that the probe was deployed.

Any pressure differential within the probe assembly that was caused by the inner and outer tubes being deployed would be equalized through the inward vent valve.

RETRACTION

When retraction was selected and the electrical circuit was made such that it would energize one of the refuelling valves within the aircraft's system, this was necessary to permit the probe assembly to relieve the fuel pressure due to retraction. Concurrent with the electrical operation, hydraulic pressure would extend both the down-latch actuator and the deployment actuator to move the probe assembly to the retracted position. At maximum actuator travel the down-latch would mechanically lock the probe assembly in the stowed position, simultaneously operating the down-latch electrical switch to de-energize the refuelling valve and make the appropriate aircraft cockpit indications.

It was also necessary that a vice versa control panel be installed to control the system, and this was considered to be the responsibility of the parent aircraft company with advice from Flight Refuelling Ltd.

To convert the aircraft for the standard in-flight-refuelling tanker role, besides modifying the fuel system, was a major installation task. The overall proposed hose-drum unit and fuel-pumping installation are shown in [Fig 310](#), together with the control panel and built-in test box. The study recommended that the new fuelhydraulic and Tensator spring motor system be employed, together with a separate power

unit, i.e. ram air turbine and fuel pump.

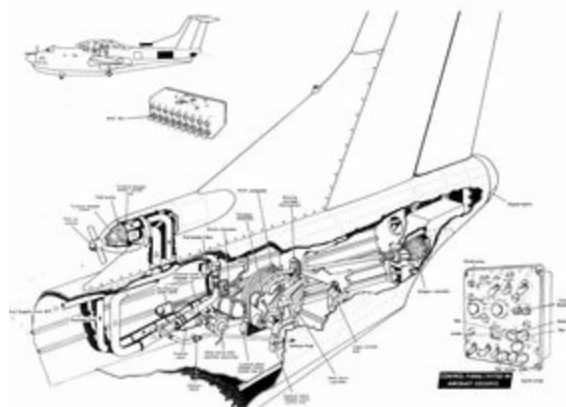


Fig. 310. Shin Meiwa US.1 tanker/receiver, hose drum and fuel-pumping installation

The power unit was to be mounted within a streamlined fairing attached to the dorsal fin above the top of the rear fuselage, the fuel pipes from the inlet and outlet of the fuel pump passing through the fuselage roof. The main fuel-supply pipe from the aircraft's fuel system ran aft along the fuselage roof, turning downwards in front of the hose-drum unit incorporating a fuel shut-off valve. It then turned forward into which were tapped a fuel pipe from the hose-drum-unit control valve and the other from the hose-drum unit's vane/motor pump, after which it turned upwards to connect with the fuel pump's inlet.

The fuel pump's outlet, after passing from the power unit, went down through the fuselage roof and thence forward for a short distance before turning aft to connect to the hose-drum unit via a venturi and fuel/vent valve. Also connected to this fuel pipe were the fuel-shock-alleviator bottle, a fuel-jettison pipe incorporating a fuel shut-off valve.

The hose-drum-unit control valve was attached to one port of the vane/motor pump, from where one line went to the fuel pump's inlet pipe, and the other to the outlet. In this

way the hose drum operated in the same manner as the Mk 32/2800 fueldraulic system and the Mk 34. However, as this installation was a variation, the hose-drum designation was given as the Mk 34/2.

The hose-drum unit in this installation was basically similar to the Mk 34 fueldraulic fuselage hose-drum unit, the difference being that the vane/motor pump unit, fuel-surge alleviator and the electronic logic box were no longer a part of the hose-drum-unit assembly. Aft of the hose-drum unit and within the aircraft's tail cone were the drogue stowage tunnel, and at its extremity at the bottom the contact lights.

The operation and control of the in-flight refuelling operated in exactly the same way as the original Mk 32/2800 equipment via the same control panel.

CHAPTER THIRTY-FIVE

Vickers VC10 C

Mk 1 Two-Point Tankers

In 1991, Flight Refuelling Aviation Ltd, based at Hurn Airport, Bournemouth, commenced converting the Vickers Type 1106 VC10 C Mk 1 transport aircraft of the Royal Air Force into a two-point tanker, while retaining its transport role. This provided the aircraft with a dual role in which it could fly with two refuelling pods, one mounted under each wing, in addition to the conveyance of freight and service personnel.

Two Flight Refuelling Ltd Mk XXXII refuelling pods were employed in this configuration, which incorporated a further operational improvement with the introduction of a fault-finding system capable of informing the operator of any malfunction within the pod. It also made use of the fuelhydraulic system to operate the hose-drum unit, the installation being similar to that of the VC10 K Mk 2 and K Mk 3 aircraft, using the same fuel-supply system within the aircraft's wings, and wing pylons, thereby making the spares for servicing the same across the tanker fleet.

Two Mk XXXII control panels were installed within the flight deck adjacent to the flight engineer's station, and similarly the closed-circuit television system, the latter enabling the operator to view the receiver aircraft when making an approach and contact.

One of the converted aircraft is shown below after its conversion, and is also shown leaving Hurn Airport for RAF

Brize Norton on 23 March 1993.

All the VC10 C Mk 1 aircraft were to be converted to the two-point configuration by the end of 1996.



The aircraft were as follows:

Vickers Type	Name	First Flight	Delivery Date	R.A.F Tail No.	Tanker Mark
1106	George Thompson VC	26-11-65	19-04-67	XR.806	C Mk 1(K)
1106	Donald Garland VC Thomas Grey VC	25-03-66	17-11-66	XR.807	C Mk 1(K)
1106	Kenneth Campbel VC	09-06-66	07-07-66	XR.808	C Mk 1(K)
1106	David Lord VC	29-11-66	21-12-66	XR.810	C Mk 1(K)
1106	Lenoe Hawker VC	11-01-67	31-01-67	XV.101	C Mk 1(K)
1106	Guy Gibson VC	05-05-67	24-05-67	XV.102	C Mk 1(K)
1106	Edward Mannock VC	14-06-67	05-06-67	XV.103	C Mk 1(K)
1106	James McCudden VC	14-07-67	03-08-67	XV.104	C Mk 1(K)
1106	Albert Ball VC	03-10-67	29-10-67	XV.105	C Mk 1(K)
1106	Thomas Mottershead VC	17-11-67	10-12-67	XV.106	C Mk 1(K)
1106	James Nicholson VC	22-03-68	17-04-68	XV.107	C Mk 1(K)
1106	William Rhodes- Moorhouse VC	07-06-68	18-06-68	XV.108	C Mk 1(K)
1106	Arthur Scarf VC	18-07-68	01-08-68	XV.109	C Mk 1(K)

CHAPTER THIRTY-SIX

Lockheed Tristar

Single-Point Tanker



Lockheed K Mk 1 Tristar single-point tanker

The contract to convert the Lockheed Tristar into a single-point tanker was given to Marshall Aerospace, Cambridge, in February 1983. The conversion was to include two additional underfloor fuel-tanks to augment the existing fuel capacity, twin air refuelling hose-drum units with drogue ejector tunnels located at the aft end of the C3 cargo bay, together with an in-flight-refuelling probe.

To understand the complete refuelling system, together with the integration with the existing aircraft fuel system, this is shown in [Fig 311](#).

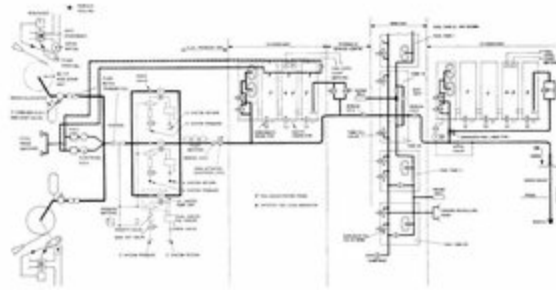


Fig. 311. Lockheed Tristar tanker, overall fuel system

From the fuel system figure it will be seen that the incorporation of the new air refuelling system and the additional fuel-tanks were an enormous design and installation task. The refuelling probe performed exactly the same operation as the standard aircraft ground refuelling connection, and so it could replenish all aircraft fuel tanks. The probe was mounted externally of the fuselage above the flight deck, offset to the starboard side and angled down some seven degrees, as shown below, the detail of which is shown in [Fig 312](#).



Tristar aerial refuelling probe

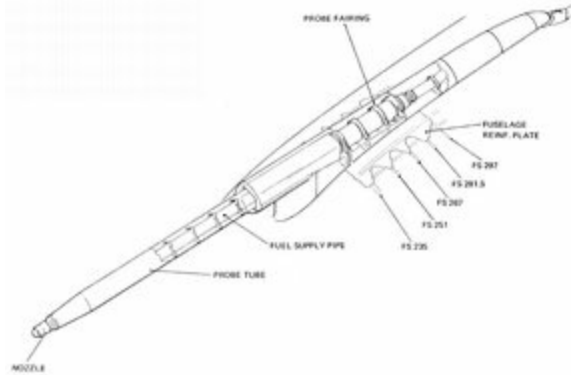


Fig. 312. Detail of Tristar aerial refuelling probe

A standard Flight Refuelling Ltd Mk 8 probe nozzle was attached to the probe structural tube and fuel pipe. The pipe was double walled, and passed through into the fuselage aft of the flight deck; it was then taken along the cabin, down a duct to below floor level, and thence into the aircraft's fuel system. A non-return valve was fitted within the fuel pipe aft of the probe nozzle, thus preventing any leakage of fuel if the aircraft lost the probe nozzle inadvertently. A fairing was incorporated over the probe tube and attached to the top of the fuselage, which had reinforcing plates fitted. The probe assembly could be removed if required, and replaced by flush-fitting blanking plates. The fuel pipe ran aft, as shown in [Fig 313](#), and aft of the cabin a further non-return valve was fitted to it. The pipe was then bifurcated, one bifurcation connecting with one of the additional underfloor fuel-tanks located in the C1 cargo bay and designated as Fuselage Tank 4F, and the other went to the aircraft's cross-feed piping and to the second additional underfloor fuel-tank located in the C2 cargo bay, designated as 4A. The bifurcation to the 4F fuel tank was again bifurcated, one feeding to a collector tank within the tank containing duplicated refuelling shut-off valves and fuel pumps, the other to the front of the tank, likewise containing duplicated refuelling shut-off valves; these were controlled via two fuel-level float-switches also fitted in the tank.

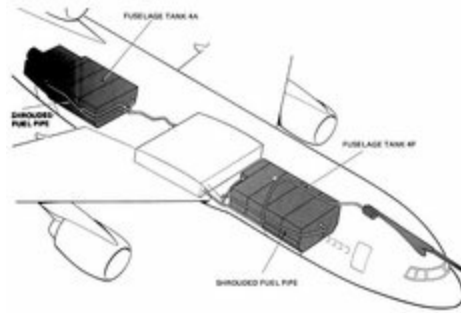


Fig. 313. Tristar aerial refuelling pipe-run from the probe

A drain pipe for the probe fuel pipe was incorporated between the two non-return valves within the line, and was led into the fuel collector tank at the aft end of the 4F fuel tank, having a manually operated fuel shut-off valve incorporated.

The probe fuel line then continued aft, connecting with the aircraft's cross-feed pipe refuelling the existing aircraft tanks via duplicated refuelling valves. Aft of this a further manually operated fuel shut-off valve was incorporated, whence the fuel pipe continued aft, feeding the 4A aft additional fuel-tank in the C2 cargo bay, and then to the twin refuelling hose-drum units. The connection to the 4A tank was similar to that of the 4F fuel-tank, it being fed to a fuel collector at its aft end and at the forward end, each having duplicated refuelling valves controlled by two fuel-level float-switches.

The forward 4F fuel tank comprised four fuel cells and a collector tank, while the aft 4A tank comprised three fuel cells and its collector tank. The capacity of the 4F tank was 7,371 imperial gallons (33,169 litres), while the 4A tank was 5,136 imperial gallons (23,112 litres), thus providing an additional 12,507 imperial gallons (56,281 litres) of additional transferable fuel.

The fuel-tank's flexible synthetic bag liners, as shown in [Fig 314](#), were fitted within a reinforced box-like structure, as

shown in Fig 315, together with a typical construction of a fuel cell. The bag liners were attached inside each tank structure by studs and fasteners, and could be removed, if necessary, through tank-to-tank apertures in each cell, so that the entire fuel-cell structure did not have to be removed if the liners had to be replaced.

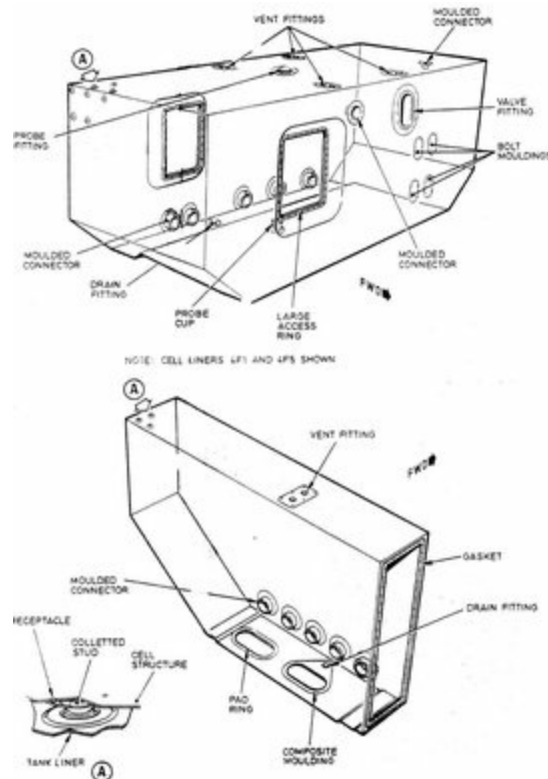


Fig. 314. Tristar flexible fuel-tank bags

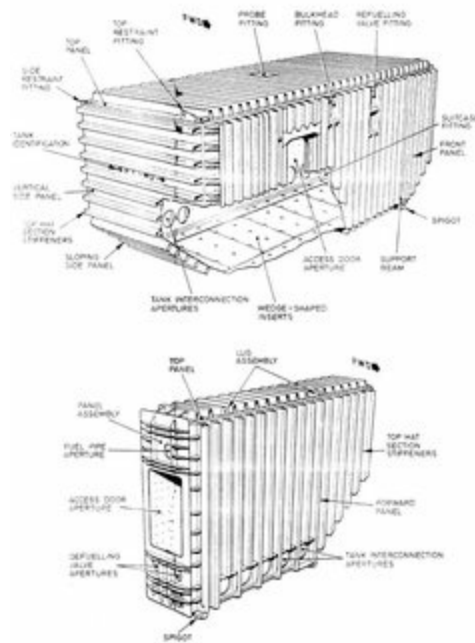


Fig. 315. Tristar fuel-tank structure

The box structures were dimensioned to fit through the existing underfloor compartment door (C1 forward, C2 aft), and were slid into position fore and aft on rails. The fuselage structure beneath the new fuel-tanks had to be reinforced, as the additional weight exceeded that for which the cargo compartments had been designed. The new tanks when fitted into the aircraft structure were restrained by various fittings, as shown in Fig 316, which illustrates these, together with the rails for sliding the tanks into position.

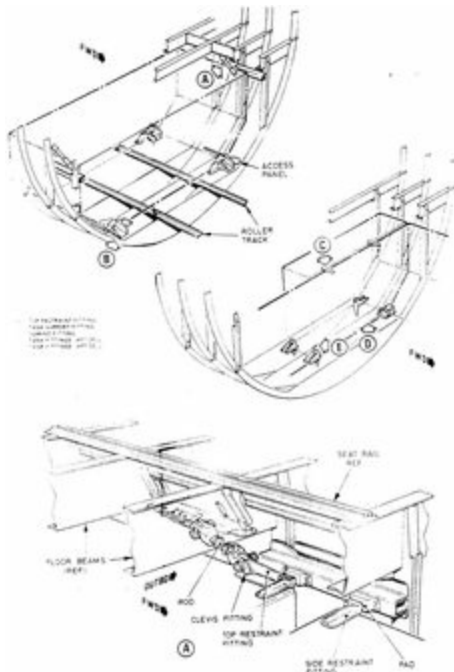


Fig. 316. Tristar fuel-tank attachments

The method of loading them into the compartment was by using a small mobile crane to hoist the fuel cell to the entrance of the cargo compartment, and then sliding it into position on the rails, as shown below.



Loading Tristar fuel cell into cargo compartment

In the forward fuel cells of the underfloor fuel tank 4F, interconnecting pipes connected the four cells to the

collector tank. In the bottom of each cell a condensate drain and gravity drain were fitted. The front cell was connected to two externally fitted, electrically operated fuel shut-off valves, which were in turn connected to the tank's ground refuelling line and the in-flight-refuelling probe piping. The fuel cell adjacent to the forward cell incorporated two high-level float-switches, and at a lower level a flap valve was fitted to the interconnecting fuel pipe. The collector box contained the fuel pumps to transfer the fuel to either the aircraft's engine supply line or to the twin hose-drum units. The pumps were also connected to two externally located fuel shut-off valves, which were also connected to the ground refuelling and probe fuel line. A small fuel line was connected from the bottom of the collector box via a manually operated fuel shut-off valve to a small pump. The inlet of the pump joined the probe fuel line downstream of a non-return valve, thus permitting the probe line to be drained of fuel during any ground servicing. A similar arrangement was contained within the aft 4A underfloor fuel-tank. However, an additional small fuel line was connected to the top of each fuel cell, which came from two 5 psi (0.34 bar) pressure-switches; a further line entered the fuel cells from the pressure-relief valves incorporated in the hose-drum unit's overpressure line.

Located aft of the 4A rear fuel-tank in the aircraft's C3 cargo compartment was a pressure box containing the twin Mk 17T hose-drum units. The box was necessary as the aircraft's underfloor cargo compartments were pressurized in common with the passenger cabin, while the hose-drum units were required to operate at the exterior atmospheric ambient pressure. The pressure box was therefore designed to maintain the external ambient pressure internally, and accept the aircraft's pressurization externally. It was therefore necessary that all connections to the box, i.e. fuel, electrical, ram air, hydraulics and the drogue ejection tunnel, had to have pressure-tight joints. The twin hose-drum units are shown in [Fig. 317](#)

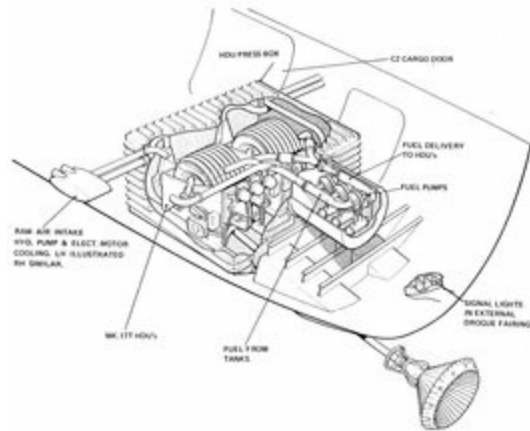
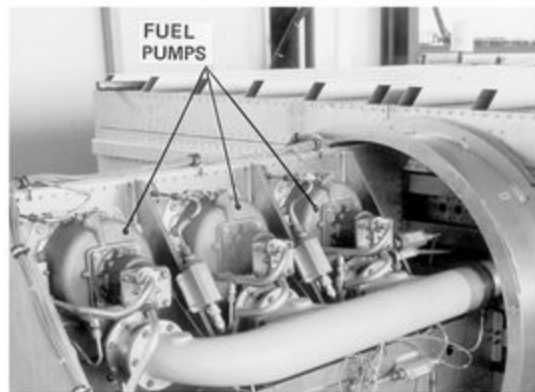


Fig. 317. Tristar twin hose-drum unit installation

Attached to the rear face of the pressure box was the fuel-transfer pump housing, which was circular in shape, and because of this it became known as the 'Dustbin' (see below). The fuel-transfer system was connected to it via an electrically actuated fuel shut-off valve and a manually operated valve, whence the fuel line connected to a manifold fuel pipe, as shown in [Fig. 318](#).



Aerial refuelling fuel-transfer pumps

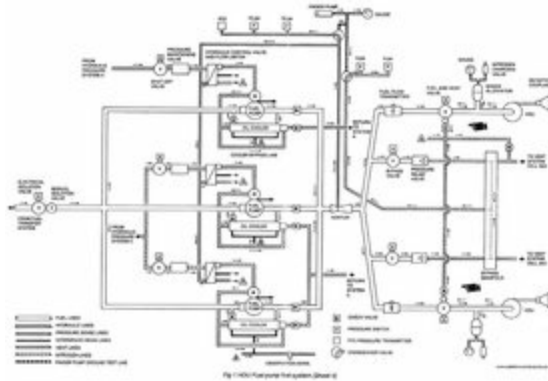


Fig. 318. Aerial refuelling fuel-transfer system

The manifold pipe was joined to three Carter hydraulically powered pumps mounted within the dustbin, these transferring the fuel during a refuelling operation. Two of the pumps were supplied with hydraulic power from the aircraft's 'C' hydraulic system, and the third from the aircraft's 'A' system, as shown in [Fig. 319](#).

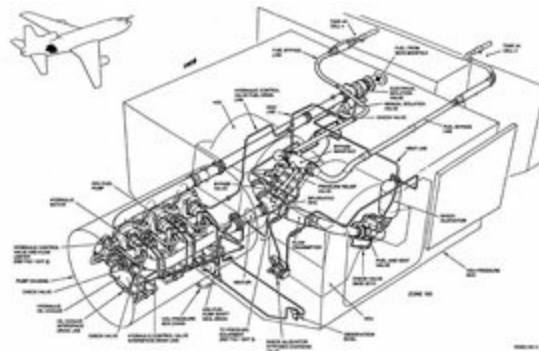


Fig. 319. Aerial refuelling transfer fuel-pump system

In each fuel pump's driving motor inlet line from the aircraft system was incorporated an electrically actuated shut-off valve, a priority valve and a hydraulic flow-limiting valve; the latter being sensed from the fuel-transfer venturi. The outlet from the hydraulic motor was connected to a fuel-cooled hydraulic oil cooler, and thence through a non-return valve

to the aircraft's hydraulic-system return lines.

The three Carter pump outlets were joined to one main fuel-transfer line having a non-return valve incorporated in each, and thence through a venturi to the hose-drum units. The venturi sensed the fuel pressure at the reception coupling of the hose-drum unit, having a pressure-sense line at its throat, and this was joined to the hydraulic flow-limiting valve, so controlling the speed of the Carter fuel pumps via the rise and fall in fuel pressure at the reception coupling, and therefore the fuel flow to the receiver aircraft. Also incorporated in the sense line were three pressure-switches, which were operated in the event of high fuel pressures being sustained at the venturi throat during a fuel transfer, which would shut down the hydraulic system to the fuel pumps, thus stopping the fuel transfer and allowing the pressure to fall.

From the venturi the fuel line was bifurcated, feeding the twin hose-drum units. Incorporated in each of these lines were a fuel-flow transmitter, a combined fuel and vent valve and a fuel-surge-shock-alleviator bottle. Also teed into the main fuel line were two vent lines; these were also bifurcated, each having an actuated fuel shut-off valve and a pressure-reducing valve. The two outlets from the valves were fed back to the three underfloor fuel-tanks in Cargo Bay C3, where they joined the vent system. Tapped into the pressure-reducing outlet lines were two 5 psi pressure-switches.

The twin hose-drum units, as shown below, were located side by side within the pressure box, and access to them was via a large access door in the starboard side of the box structure, which also permitted their removal.



Tristar drogue-ejector tunnels

Although the units were located side by side, there was a 7-inch lateral stagger between the drogue-ejector tunnels. The reason for this was due to the drogue tunnels being offset to the port side of the hose-drum-unit's centre line (the later being equally spaced to each side of the aircraft's centre line). This was necessary to line up the refuelling hose, which, when fully trailed, was biased to the port side of the hose-drum-unit's centre line. It therefore followed that the exit of the port hose-drum unit was farther

from the aircraft's centre line than that of the starboard. This can clearly be seen below in which the ejector tunnels are visible. The curvature and taper of the underside of the fuselage was such that the stagger between the drogue exits required the fuselage skin to be cut for these apertures; it was necessary to totally redesign five frames of the aircraft's structure aft of the pressure box, and add three layers to reinforce the aircraft's skinning externally. Because the aft-end drogue tunnels protruded beyond the aircraft's bottom skin line, fairings had to be incorporated, as shown below.



Drogue tunnel fairings



Tristar tunnel fairing and contact lights

To ensure rapid deployment of the drogue from the tanker aircraft, Flight Refuelling Ltd designed an ejector tunnel to operate in conjunction with the Mk 17T hose-drum unit. The tunnel comprised a glass-fibre-reinforced spun tube, which carried internally an ejector assembly.

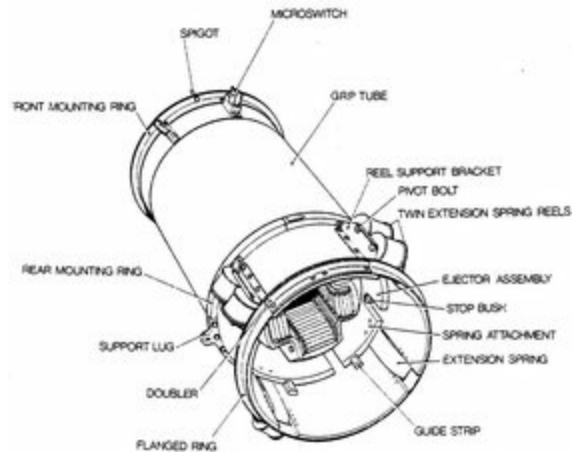


Fig. 320. Mk 17T drogue ejector tunnel

The basic tunnel was fitted with external machined rings at each end, and a third mounting ring forward of four extension spring reels at that point were equally spaced externally around the periphery of the basic tunnel and attached at the rear end. Five stop-bushes were also secured internally at the rear end of the tunnel between the rear machined and mounting rings. These were to limit the travel of the ejector assembly when the drogue had been ejected and was in its extended position (rearwards). Two proximity switches were fitted at the front end of the tunnel, which cut the electrical power supply to the hose drum's driving motor prior to the reception coupling and drogue being fully stowed. The tunnel was mounted to the aircraft's structure via two spigots at the forward end and two support lugs on the other mounting ring.

Internally three longitudinal strips were equally spaced round the interior, which provided an easy sliding operation for the ejector assembly.

The overall dimensions of the complete assembly were:

Length	41.00 inches (1,047.4 mm)
--------	---------------------------

Diameter over mounting rings	019.82 inches (503.4 mm)
Width across support lugs	22.31 inches (566.7 mm)
Weight	156 lb
Eject load	220 lb/ft

The ejector assembly ([Fig 320](#)) within the tunnel was a large machined thrust ring, which incorporated four sets of plastic roller chains through which the refuelling hose travelled. Eight tension springs of the Tensator type, in four sets of four, were secured to the outer periphery of the thrust ring from the externally mounted spring reels on the tunnel. Three longitudinal equally spaced slots were machined on the thrust ring periphery, allowing the assembly to slide easily over the plastic runners within the tunnel. Similarly five cut-outs in the forward face provided the abutment for the five stop-bushes.

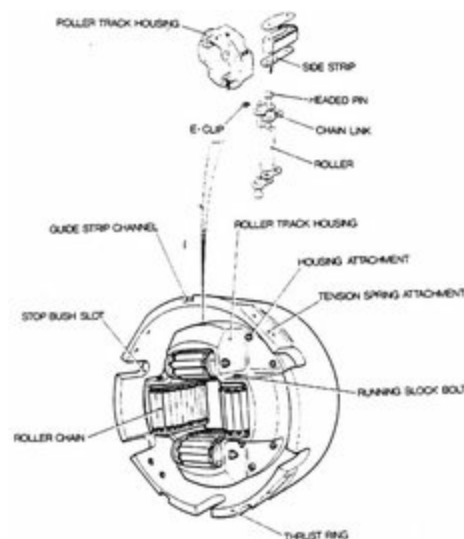


Fig. 321. Mk 17T hose-drum-unit ejector assembly

The principle of operation of the complete tunnel assembly via the electrical operation of the hose-drum unit was as follows:

When the hose-drum unit was operated in the 'Trail' mode, the ejector assembly reacted against a push ring on the unit's reception coupling (Fig 321) through the tension applied by the eight Tensator springs. These pulled the ejector assembly rearwards, thrusting the reception coupling and drogue into the tanker aircraft's slipstream, thus causing the drogue to deploy. The ejector assembly slid within the tunnel until it abutted the five stop-bushes.

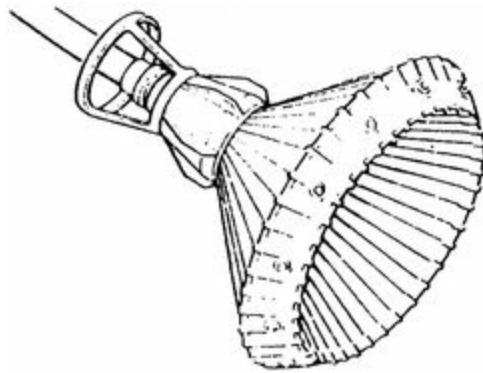


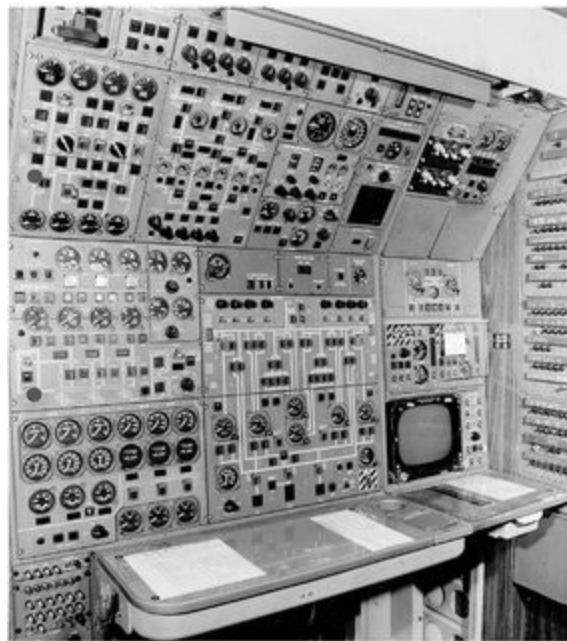
Fig. 322. Mk 17 reception coupling push ring

When the hose-drum unit was operated in the 'Wind' mode, the reception coupling push ring abutted the ejector assembly, the assembly being pulled forward via the hose-drum unit's wind effort, unwinding the Tensator springs from their spring reels and thus applying a load in the opposite direction, until the ejector assembly operated the proximity-switches, which in turn selected the hose drum's driving motor to 'OFF', the hose-drum unit's brake holding the reception coupling and drogue in the 'Stowed' position.

Ram air was provided for the Mk 17T hose-drum unit's driving motor and fluid drive oil system via a ram air intake incorporated in small vane-like fairings; these protruded

from both port and starboard sides of the fuselage. The two intakes of these were connected to the hose-drum unit's pressure box by two pipes via sealed connectors, one of the pipes being connected to the driving motor's ram air intake, the other to the hose-drum unit's cooler via a large duct. The cooling air, having passed through the motor and cooler, was exhausted into the pressure box's interior.

While describing the in-flight-refuelling equipment installation it is interesting to note that the three Pan American aircraft did not have the C3 cargo door. Therefore a modified variant was proposed by Marshall Aerospace, in which one of the fuel cells in the 4A fuel-tank would be deleted. This then permitted the aircraft's C2 cargo door to be used to load the the hose-drum-unit pressure box. Also, for centre-of-gravity reasons, one of the 4F tank cells would have to be deleted. These changes would reduce the aircraft's fuel capacity by about 12,250 imperial gallons (5,625 litres), and this was one of the reasons for the K Mk 2 variant.



Tristar flight engineer's console

Control of the in-flight-refuelling system was by the aircraft's flight engineer. Two hose-drum-unit control panels were located above a CCTV monitor, the latter for viewing the receiver aircraft during a refuelling operation, as shown below.

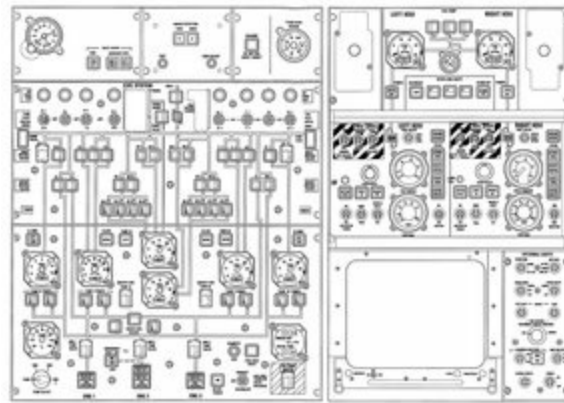


Fig. 323. Tristar hose-drum-unit control panels

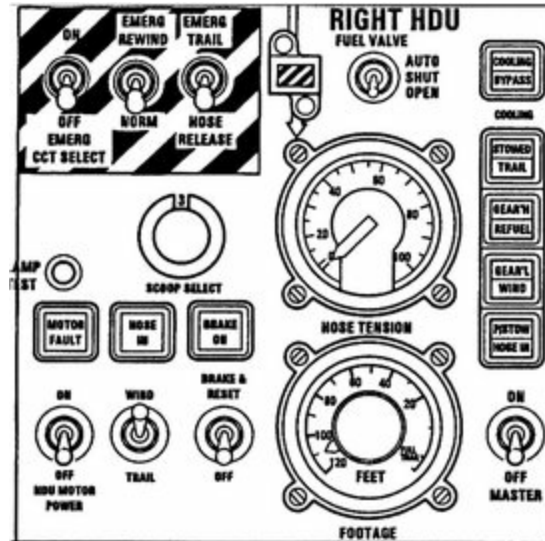


Fig. 324. Tristar hose-drum-unit control panel (right-hand panel illustrated)

The control operation of the Mk 17T hose-drum unit was identical to that of the Mk 17B hose-drum unit; therefore the

switching was similar; however, the Tristar control panels were of a smaller and more up-to-date design.

At the top left-hand side were three emergency switches. The first was capable of selecting the circuit selector within the hose-drum unit's electrical circuit, the second provided the capability of an emergency hose rewind, and the third emergency trail released the hose-drum brake and hose release, providing power to the hose-drum jettison mechanism. To the right of these was the fuel and vent valve switch providing an automatic selection during a refuelling operation, or a manual fuel-valve-shut and a manual open selection.

To the right of this switch and in a vertical alignment were indicator lights providing visual information on:

1. Hydraulic cooling for the fuel-pump motors
2. Whether the refuelling hose was stowed or in the trailing mode
3. Hose-drum-unit gearbox, high gear/refuel
4. Hose-drum-unit gearbox, low gear/wind
5. Refuelling hose, pre-stow/hose in.

Beneath these was the hose-drum-unit master switch for selecting the electrical power supply to the unit.

Below the three emergency switches were a test lamp and the hose-drum unit's Fluidrive scoop control; this was calibrated numerically to conform to the aircraft's airspeed, thus providing the correct hose tension throughout the refuelling operation. There were also three indicator lamps and switches, the first a hose-drum-motor fault-indicator lamp and hose-drum-motor power ON/OFF switch, a HOSE IN indicator lamp and TRAIL/WIND switch, and thirdly a hose-drum-brake ON indicator lamp and BRAKE RESET switch.

Finally, to the right of these were the HOSE TENSION indicator in amperes, and HOSE FOOTAGE indicator, to

show how much hose was on the hose drum.

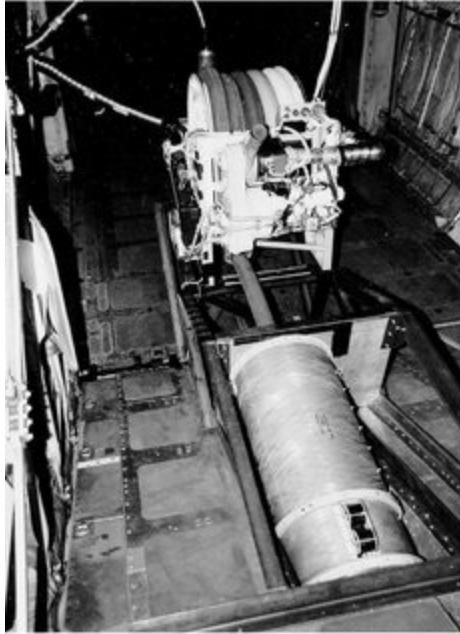
CHAPTER THIRTY-SEVEN

Mk XVIIT Hercules

Tanker Tristar Trials

During the latter end of 1983 the prototype Mk XVIIT hose-drum unit and the drogue ejector tunnel were installed in a Royal Air Force C Mk 1 Hercules aircraft XV.177. The installation was for trial purposes, initially to prove the combination of the Mk XVIIB refuelling hose and a Mk XXXII-type drogue to establish the stability through the speed range and altitude ranges. The trial was a preliminary development run prior to the equipment being installed in the new Tristar tanker that was under conversion at the time.

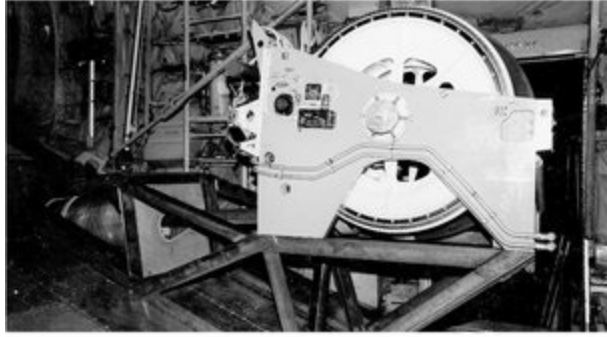
The Mk XVIIT hose-drum unit and the ejector tunnel were installed on the port side of the Hercules cargo ramp within the fuselage.



Mk XVIIT hose-drum unit in Hercules

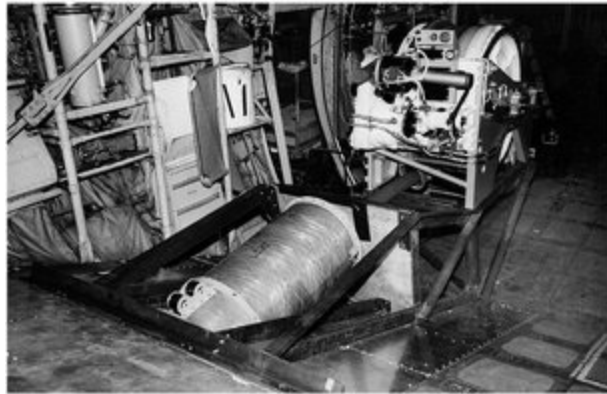
The installation represented the side-by-side configuration, not only for the Tristar, but also for a Hercules conversion, and not only for the Royal Air Force, but also for overseas customers.

No fuel system was included in this installation, but the refuelling hose was primed with fuel, thus providing the operational weight and stiffness during a refuelling operation. The drogue ejector tunnel eliminated the necessity for a drogue box as in the Operation Corporate conversion, and this resulted in a flush installation on the outer lower surface of the aircraft's cargo ramp. The hose-drum unit was mounted to a welded structural framework, as shown below, and likewise the ejector tunnel, also as shown below.

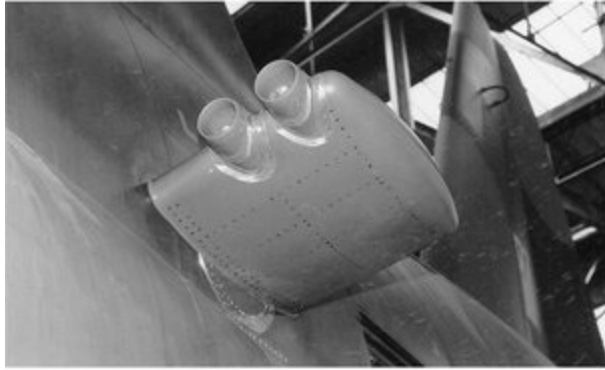


Mk XVIIT hose-drum unit on structural framework

Mk XVIIT ejector tunnel installation on Hercules

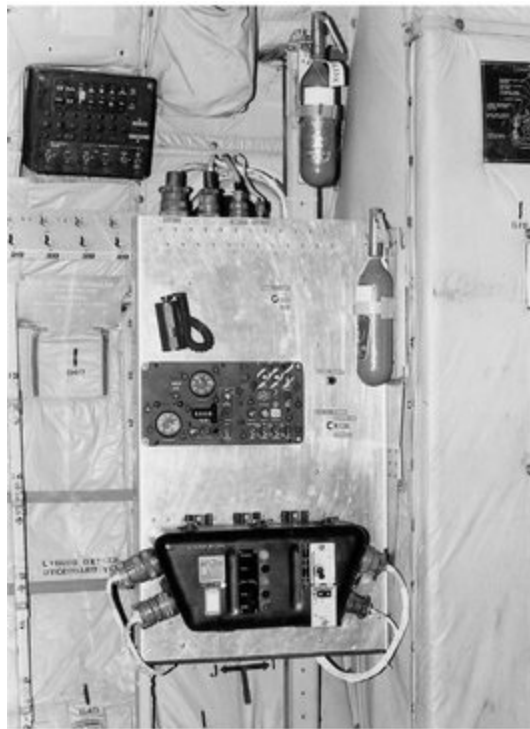


The cooling air for the hose-drum unit's driving motor and oil cooler were ducted through two flexible pipes to the port side of the fuselage forward of the rear door. The two ducts passed through the aircraft's skin into a streamlined ram air fairing and thence to two ram air intakes.



Mk XVIIT ram air intakes on Hercules

The standard Mk XVIIB control panel and relay box were mounted on the port side of the fuselage, as shown below.



Mk XVIIT control panel and relay box

The flight trials commenced on 31 October 1983, and were concerned with the efficiency of the ejector tunnel and the

clearance of the drogue from the fuselage and the aircraft's tailplane, and were also to observe the behaviour of the refuelling hose/drogue combination at various trail lengths. It was found that the 'Trail' and 'Wind' characteristics of the hose and drogue were satisfactory after a trial lasting 3 hours 16 minutes.

The following is a summary of the flights that ensued:

Flight No.	Date	Duration	Receiver Aircraft
2.	1-11-83	2 hours 20 min	-
3.	3-11-83	4 hours 7 min	Hercules XV.200
4.	6-11-83	3 hours 31 min	Hercules XV.196
5.	12-11-83	3 hours 11 min	Hercules XV.187
6.	6-12-83	2 hours 14 min	-
7.	7-12-83	4 hours 13 min	-
8.	8-12-83	4 hours 6 min	-
9.	17-12-83	4 hours 26 min	Hercules XV.292
10.	21-11-83	5 hours 27 min	Canberra WK.143

The following is a summary of the receiver aircraft's pilot's comments, which showed that development flight trials are essential, particularly as trailing various pieces of equipment differs with each type of aircraft.

Flight No. 2 was a repeat of No. 1. However, some problems arose with inadvertent hose-drum brake operation, but sufficient satisfactory operations were obtained to continue.

Satisfactory contact was made at Flight Levels 100 and 200 at airspeeds of 190-260 kts.

The conclusion from this flight was that the hose-drum unit's manual scoop required adjustment for this particular refuelling hose/drogue combination.

In Flight No. 3 at Flight Level 100, contacts were made adjusting the scoop settings to achieve stable conditions, and some satisfactory contacts were

made.

Flight No. 4 was a repeat of Flight No. 3, with revised scoop settings to improve stability. Contacts were made from 190 to 260 kts. Reasonable contact was made at 280 kts, but because of hose resonance the probe nozzle was removed from the receiver aircraft.

Flight No. 5 was to set the scoop settings to establish the torque to balance drag. Difficulty was experienced in maintaining a particular setting and obtaining repeat stability at specific scoop settings.



Hercules XV.196 contacts XV.177 during the trials





The results of Flights 1 to 5 were summarized as follows.

The trial established:

Ejection system satisfactory

Trail/wind of hose/drogue combination satisfactory.

There was, however, some instability of the system when a receiver made a contact, and difficulty was experienced in obtaining a consistent scoop settings, thus further development was required.

The difficulty of adjusting the scoop setting was considered to be overcome by the introduction of a multi-turn potentiometer.

Flight 6 'Trail' and 'Wind-in' times were recorded at speeds above 260 kts to demonstrate the stability of the refuelling hose/drogue combination, still using the Mk XXXII-type drogue. The flight confirmed that refuelling could be achieved above 260 kts at Flight Level 100, but with a multiplicity of scoop settings, it became evident that the stability could be improved by increasing the drag of the drogue. It was decided that for the next flight a higher-drag drogue would be used.

Flight 8, with a higher-drag drogue, demonstrated the increased refuelling hose/drogue stability over the speed range 170-260 kts, together with a reduced number of scoop

settings, and was considered satisfactory to check the system with a receiver aircraft.

Flight No. 9 with Hercules XV.292 as a receiver demonstrated successful dry contacts over an airspeed range of 170–265 kts at Flight Level 100. The scoop settings were easily controllable and successful refuelling would have been achieved.

Flight 10 using Canberra WK.143 as a receiver demonstrated successful dry contacts over the speed range of 240–320 kts at Flight Level 100 and 180–320 kts at Flight Level 200.

A final check at 190 kts resulted in the probe nozzle being removed from the Canberra.

The reason for the loss of the probe nozzle was considered to be caused by a problem with the hose-drum unit, as on the previous contact it was evident the refuelling hose did not respond.

This, however, was a very successful test flight, and it was considered that the efficiency of the Mk XVIIT configuration with a refuelling hose/drogue combination using the higher drag drogue had been fully demonstrated.

Overall conclusions

The flight test programme had demonstrated that the Mk XVIIT configuration for Flights 9 and 10 gave the confidence that the installation in the Tristar K Mk 1 would be operationally successful.

The drogue/reception coupling ejection system was satisfactory for all speed ranges from 170 to 320 kts, and successful ejections had been demonstrated at all times.

The 'Trail' and 'Wind' of the refuelling hose/drogue combination was satisfactory.

The multi-turn potentiometer considerably improved the

scoop-setting adjustment. The modified higher-drag drogue operated successfully over the complete airspeed range from 170 to 320 kts.

The hose-drum unit was subjected to 100 contacts, with the refuelling hose/drogue being trailed for some thirty hours, and some damage did occur.

The lack of response during the last contact could have been caused by the first pair of rollers on the ejector system becoming seized.

The final illustration shows Hercules XV.177 trailing the refuelling hose from the cargo ramp installation.



Hercules XV.177 trailing refuelling hose from cargo ramp

CHAPTER THIRTY-EIGHT

Mk XVIIT

Hose-Drum Unit

The Mk XVIIT hose-drum unit was a derivative from the Mk XVIIB refuelling package's basic hose-drum unit for use on the Lockheed Tristar tanker.

Its origin came about through a meeting with Marshalls of Cambridge in November 1982, when it was found that Sargent Fletcher of California was in an early lead to supply the air refuelling equipment for the new Tristar tanker.

The existing British equipment, namely the Mk XVIIB refuelling package, was too large for the new Tristar requirement, which was that a twin hose-drum installation was required for redundancy purposes, i.e. if one unit failed the second could be used, thus saving an aborted refuelling operation.

It was soon discovered that the hose-drum unit was not required to trail the existing length of 80 feet of refuelling hose, but was now required to trail 70 feet.

By removing the the Mk XVIIB support structure and fuel system, thus making use of the basic hose-drum unit only, it was found that its overall size could be reduced and match the Sargent Fletcher equipment size. This was achieved by removing one layer of refuelling hose from the existing three-layer hose drum, and redesigning the hose-drum unit's side plates to accept the new drum. Within a week the revised hose-drum unit design had been completed, as shown in [Fig 325](#), in which an overlay comparison is made

between the two basic hose-drum units.

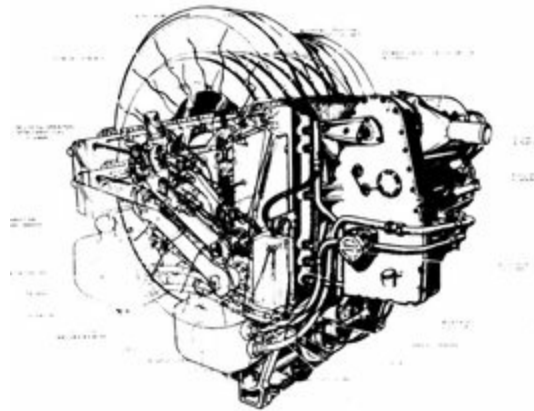


Fig. 325. Mk XVIIB and Mk XVIIT hose-drum unit comparison

The only other difference was that the fluid drive reservoir was moved forward on the port side plate, as can be seen in [Fig 326](#), the necessary oil pipes also being increased in length.

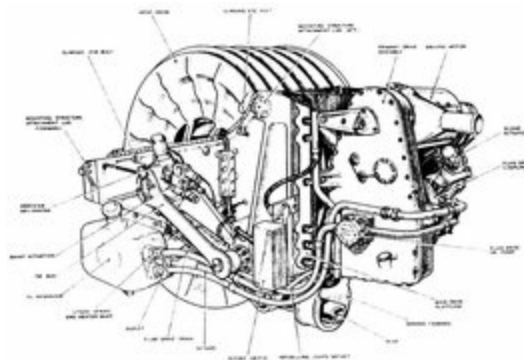


Fig. 326. Mk XVIIT hose-drum unit

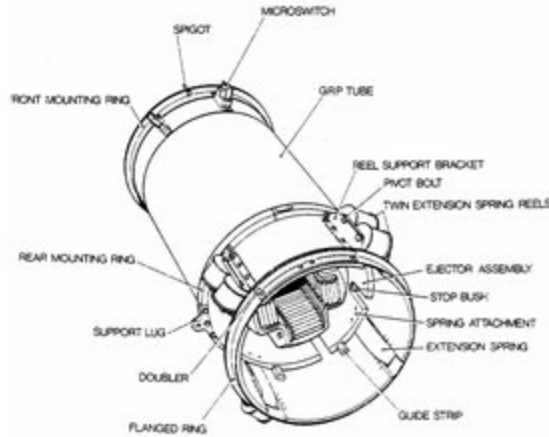
The unit would operate in the same manner as the original Mk XVIIB, although the fluid drive scoop was to be indicated by numbers corresponding to the tanker aircraft's airspeed, this being similar to that of the Valiant tanker aircraft's Mk

XVI hose-drum unit. The overall dimensions, weight and performance of the new Mk XVIIT were as follows:

All-up weight (wet)	750 lb estimated
All-up weight (dry)	630 lb estimated
Overall height	43.50 inches
Overall length	69.00 inches
Overall width	37.00 inches
Refuelling hose	3.00 inches bore x 70 feet long
Operating height	0-50,000 feet
Operating temperature	-40 to +70 °C
Operating speed	180-320 kts IAS
Fuel-transfer flow rate	0-500 imperial gallons/minute

To enable the reception coupling and drogue to be deployed from the aircraft, Flight Refuelling Ltd designed a drogue ejector tunnel to operate in conjunction with the Mk XVI hose-drum unit. The tunnel comprised a glass-fibre-reinforced spun tube that carried an internal ejector assembly, as shown in [Fig 327](#).

[Fig. 327](#). Mk XVIIT drogue ejector tunnel



The basic tunnel was fitted with external machined rings at each end, and a third mounting ring forward of spring reels; four extension spring reels were equally spaced around the tube's periphery, mounted externally of the tube between the rear ring and mounting ring. Five stop-bushes were secured internally at the rear end of the tunnel, thus limiting the travel of the ejector assembly in the extended position (rearward). Two proximity switches were fitted at the front of the tunnel, which cut the electrical power to the hose-drum driving motor prior to the fully stowed position of the reception coupling and drogue. The tube was mounted to the aircraft's structure via two spigots on the forward ring and two support lugs on the other mounting ring.

Internally three longitudinal strips equally spaced round the interior provided an easy sliding operation for the ejector assembly. The overall dimensions of the assembly were:

Length.....41.00 inches
Diameter over mounting rings.....19.82 inches
Width across support lugs22.31 inches
Weight156 lb
Eject load220lb/ft

The ejector assembly ([Fig 328](#)) operating within the tunnel was a large machined thrust ring that incorporated centrally

four sets of plastic roller chains through which the refuelling hose travelled. Eight tension springs of the Tensator type, in four sets of two, were secured to the outer periphery of the thrust ring of the ejector assembly from the externally mounted spring reels on the tunnel. Three longitudinal slots were machined on the periphery, allowing the assembly to slide easily over the plastic runners within the tunnel. Similarly five cut-outs in the forward face provided the abutment for the five stop-bushes.

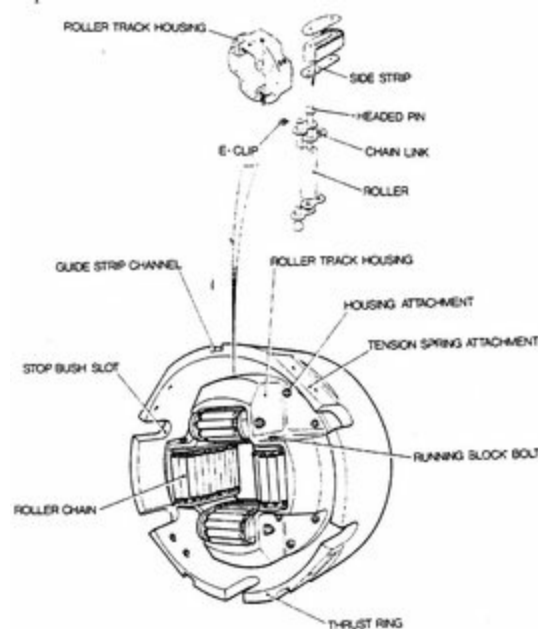


Fig. 328. Mk XVIIT hose-drum-unit ejector assembly

The principle of operation of the complete ejector tunnel assembly via the electrical operation of the hose-drum unit was as follows.

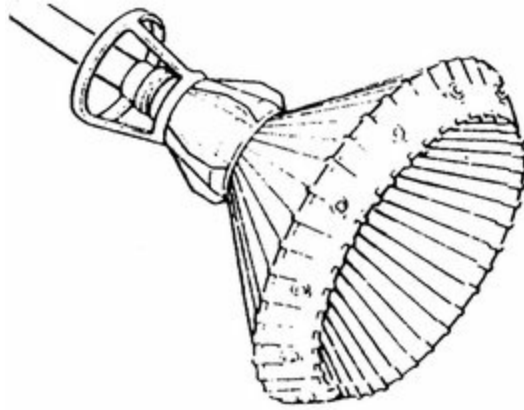


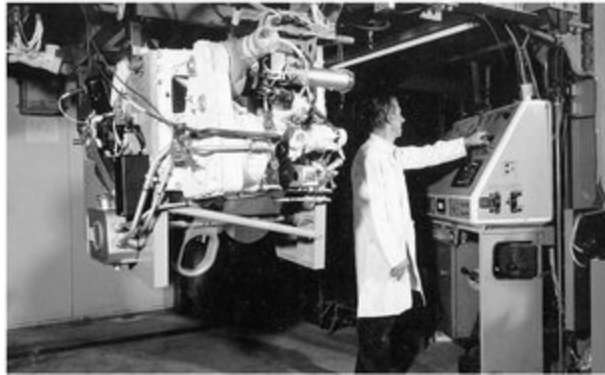
Fig. 329. Mk XVIIT, showing push ring on reception coupling

When the hose-drum unit was operated in the 'Trail' mode, the ejector assembly reacted against a push ring on the reception coupling through the tension applied by the eight Tensator tension springs. These pulled the ejector assembly rearwards, thrusting the reception coupling and drogue into the aircraft's slipstream, thus deploying the drogue. The ejector assembly slid within the tube until it abutted the five stop-bushes. When the hose-drum unit was operated in the 'Wind' mode, the reception coupling push ring abutted the ejector assembly, and the assembly was pulled forward via the refuelling-hose wind effort, unwinding the Tensator springs from their spring reels and thus applying a tension load in the opposite direction, until the ejector assembly operated the proximity switches, which in turn selected the hose-drum unit's driving motor to 'OFF'.

Initially to ground test the Mk XVIIT hose-drum unit and drogue ejection tunnel, the unit was located in an existing test rig at Flight Refuelling Ltd, as shown together with its control panel, and the ejection tunnel assembly located in a test rig positioned in the manner that it would be in the aircraft installation.

The reception-coupling push ring for testing purposes was attached to a dummy reception coupling, which in turn was secured to a tubular strut connected to the end of the

refuelling hose.



Mk XVIIT hose-drum unit in test rig



Mk XVIIT hose-drum unit in test rig.

CHAPTER THIRTY-NINE

Boeing 707 Tanker

The Peruvian Air Force in 1985 requested Israeli Aircraft Industries of Tel Aviv to convert one of the military Boeing 707 aircraft into a three-point tanker ([Fig 330](#)).

The equipment to be installed comprised two Flight Refuelling Ltd Mk 32/2800 wing refuelling pods, one of each being mounted beneath the aircraft's wing at the wingtip, the new Mk 34 fuselage hose-drum unit located within the aircraft's rear pressurized cargo compartment, together with a drogue stowage tunnel, and three control panels located on the flight deck.

The overall concept of the fuselage installation is shown in [Fig 331](#), in which the drogue tunnel, although based on the Tristar tanker's tunnel, featured an additional roller track refuelling hose

guide at the forward end, and a brush seal where the hose entered the tunnel, thus ensuring that the aircraft's pressurization was maintained within the cargo compartment.

The new Mk 34 hose-drum unit ([Fig 332](#)) was a derivative of the Mk 32/2800 wing pod employing the same fueldraulic system and Tensator spring motor for the refuelling-hose response when a receiver aircraft made a contact. The basic hose drum, however, had an additional feature in that it could accept 70 feet of refuelling hose rather than the 50 feet as on the existing wing pod. The drum was also designed to be interchangeable with the Mk 32/2800 wing

refuelling pod.

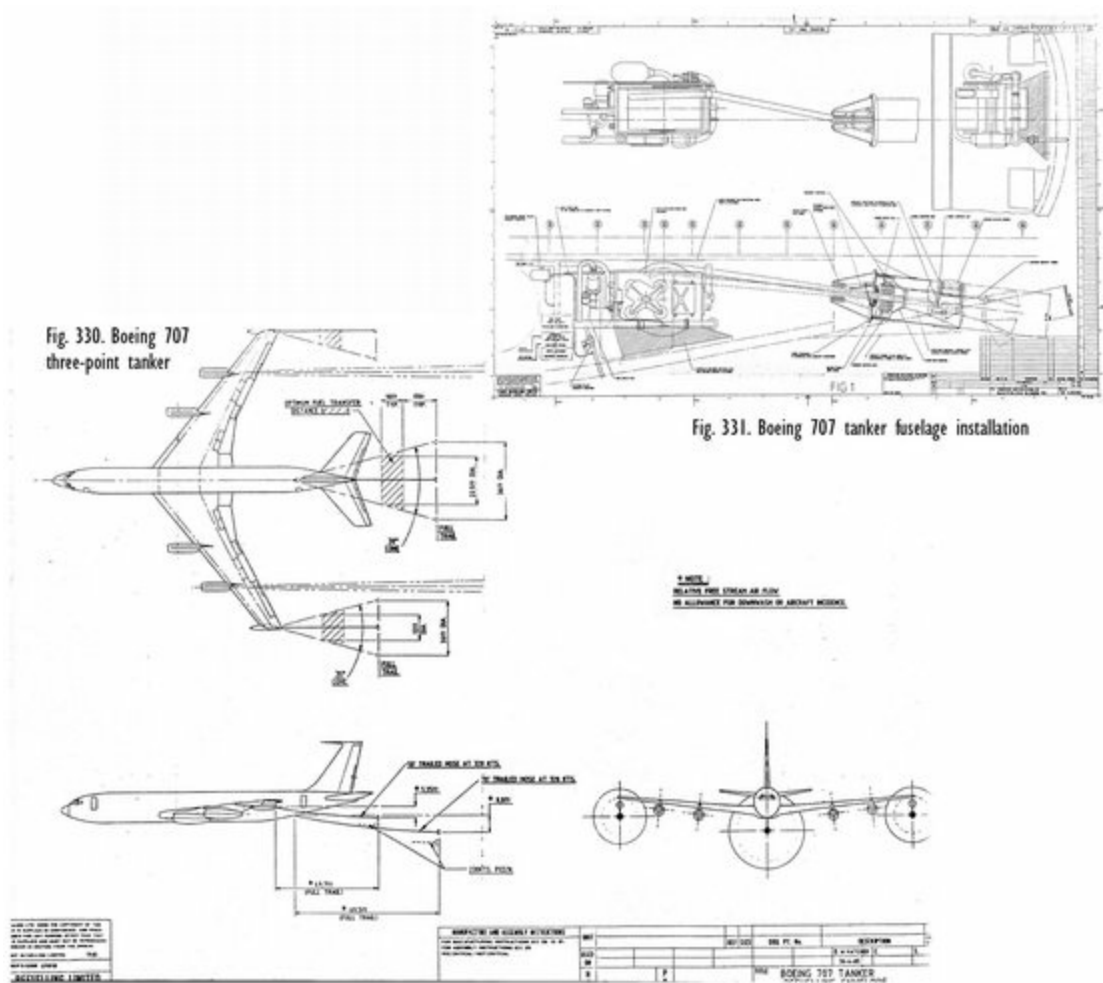


Fig. 330. Boeing 707 three-point tanker

Fig. 331. Boeing 707 tanker fuselage installation

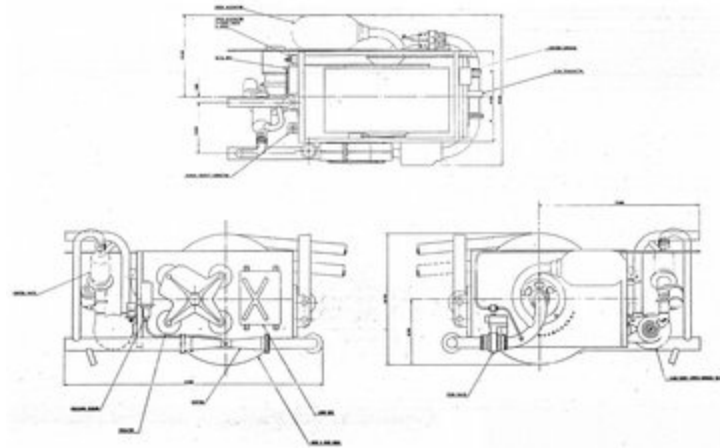


Fig. 332. Mk 34 hose-drum unit

The fuel transfer system was in principle the same as for the Mk 32/2800 wing refuelling pod. However, the fuel pump for the fuel transfer and powering of the hose-drum unit was driven via the aircraft's hydraulic system and was a separate package mounted to the aircraft's structure on the port side.

The package comprised the fuel pump with a hydraulic motor, a hydraulic flow-control valve and the necessary servo amplifiers for signalling, which are shown in block form in the fuel-transfer-system diagram (Fig 333).

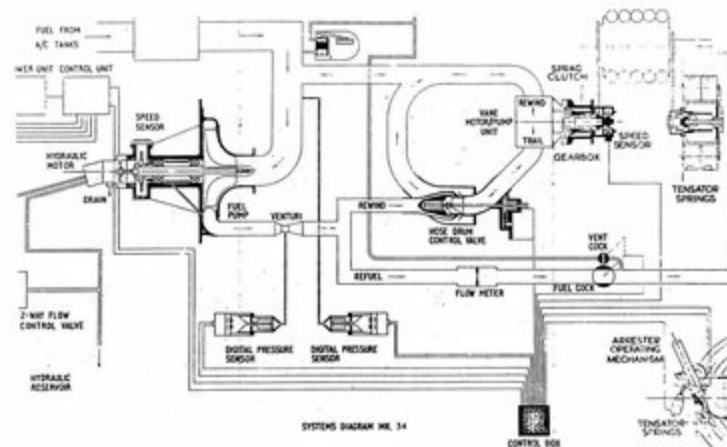


Fig. 333. Mk 34 hose-drum-unit fuel-transfer system

The fuel pump was basically a Plessey Ltd Type 7312 with a conversion for the hydraulic drive motor. The conversion was achieved by replacing the ram air turbine power source with an adaptor housing and a linear transducer, the latter to signal via the servo amplifiers the hydraulic control valve. The speed sensing was identical to the Mk 32/2800, thus permitting the same items of spares to be used.

The hydraulic flow-control valve was fitted in the hydraulic inlet to the fuel pump's motor with an outlet to the hydraulic return line. The valve acted as a bypass to control the fuel pump's speed, its position being signalled via the servo amplifiers. The operation of the fuel-pump package was exactly the same as the Mk 32/2800, fuel pressure being sensed at the throat of a venturi to a pressure sensor, which provided pressure information in a digital form to the control system, thereby adjusting the fuel-pump speed via the linear transducer, thus positioning the hydraulic flow-control valve to the correct setting. Similarly the speed sensors on the fuel pump signalled the hydraulic control valve either to maintain the maximum speed of 6,900 rpm or to provide a fuel-pump shut-down in the event of it overspeeding to the limit of 7,200 rpm. A further fuel-pressure sensor was fitted in the inlet to the fuel pump, which signalled when low fuel-inlet pressure occurred, thereby shutting down the pump to prevent cavitation.

The drogue ejector tunnel ([Fig 334](#)), although based on the Tristar's design, was capable of accepting the differential air pressures caused by the aircraft's cabin air pressure acting externally upon it, and the ambient atmospheric pressure acting internally at altitude.

The tunnel assembly comprised a rolled aluminium tube (the Tristar being spun glass-fibre) that carried an internal ejector assembly. The tube assembly was secured to the aircraft's structure in a similar manner to that of the Tristar's installation and aft of the hose-drum unit (Mk 34). The ejector operated within the tunnel, and incorporated the

same sets of roller tracks through which the refuelling hose travelled, as well as the eight Tensator tension springs in four sets of two, secured to the ejector, and coiled on the eight spring reels attached externally to the tunnel. Upon releasing the hose-drum brake, the reception coupling and drogue were ejected into the aircraft's slipstream, similar to

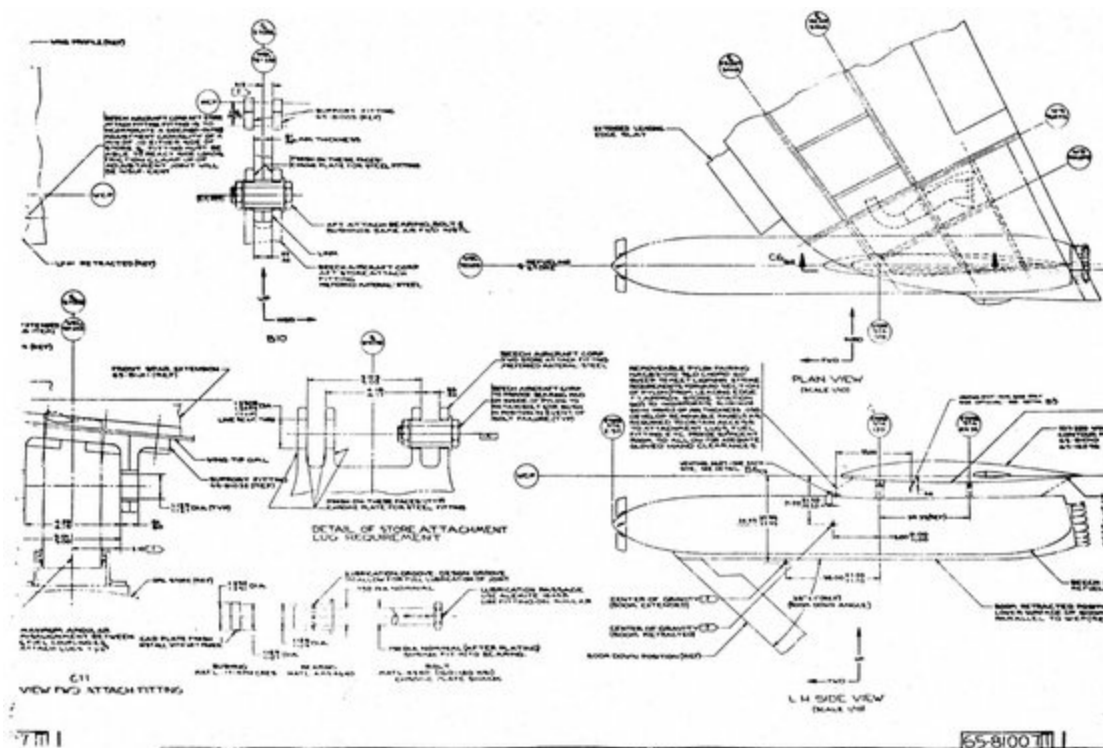
Fig. 334. Boeing 707 tanker drogue ejector tunnel

the Tristar. The two sets of proximity switches that were located at the forward end of the tunnel and operated by the ejector signalled the hydraulic flow-control valve to shut down the fuel pump, and apply the hose-drum-unit brake at the pre-stow position of the reception coupling and drogue during the winding-in sequence.

aperture, thereby preventing the escape of cabin air-pressure. Forward of the flap a further set of roller tracks were incorporated to feed the refuelling hose onto the hose drum.

The Mk 32/2800 wing refuelling pod installation was located at the aircraft's wingtip, similar to that carried out on the Boeing 707-3J9C tanker transport aircraft, as shown in [Fig 335](#), which incorporated the Beech refuelling pod.

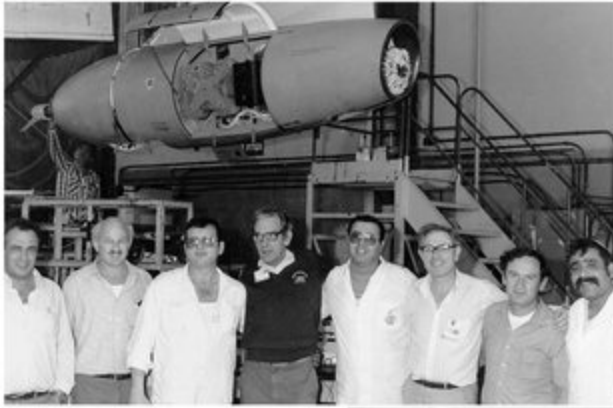
Fig. 335. Typical refuelling pod on Boeing 707 wing pylon



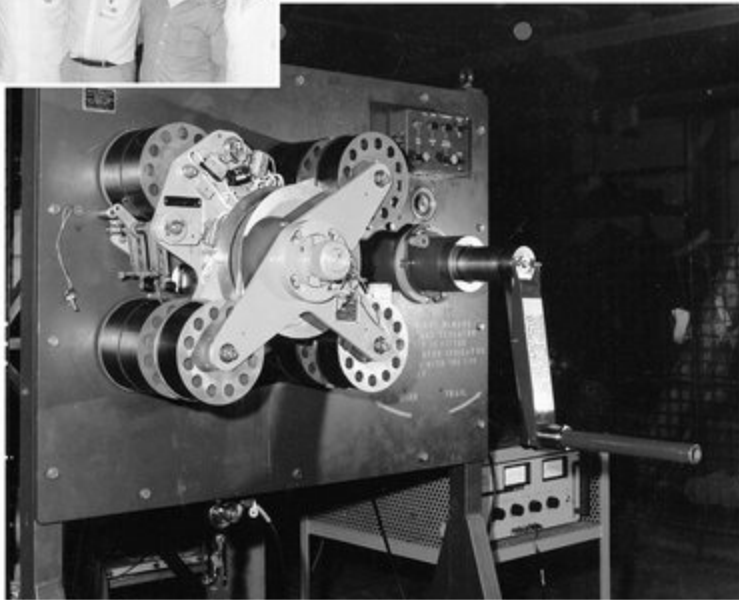
Israeli Aircraft Industries redesigned the pylon to suit the Mk 32/12800. During the installation programme, Mr R. Young, Mr D. Lloyd and I, all of Flight Refuelling Ltd, met Mr M. Kovo, the Israeli engineer in charge of, not only the installation, but also the initial ground testing and flight testing, as well as other personnel who were involved, as shown below.

I was fortunate to be included in the flight testing throughout day and night operations. The Mk 32/2800 wing pod met the day and night performance requirements, with contacts being made with A-4 and F-4 Phantom aircraft of the Israeli Air Force.

The Mk 34 fuselage unit, however, was found to be sluggish in the response sequence of operation when a receiver made a contact. The installation of the fuselage unit permitted visual observation during the complete operational sequences of the hose drum. It was apparent that the Tensator spring motor did not have sufficient power to provide a quick response when a receiver made a contact. The Tensator unit was removed from the hose-drum unit and returned to Flight Refuelling for further investigation. The conclusion drawn from the investigation was that additional springs were required to provide extra effort. Three additional spring reels were added to the outside of the existing assembly, as shown below. The additional spring installation was designed to be easily removable, thus permitting access to the original set of springs in the event of a failure. The new Tensator spring assembly was fitted to the hose-drum unit, and then test flown, showing a great improvement and meeting the response requirements.



D. Lloyd and myself with the
installation team



Mk 34 hose-drum unit's
modified Tensator unit

CHAPTER FORTY

Mk 34 Hose-Drum Unit

The Mk 34 hose-drum unit was a derivative of the Mk 32/2800 wing unit for fuselage installation, as shown in [Fig 336](#), and used the new fuelhydraulic system for powering the hose-drum unit and the transfer of fuel, also incorporating the Tensator motor spring system for the refuelling-hose response. The fuel pump's power source was a separate package assembly to be located in a convenient position in the tanker aircraft, and was supplied with fuel from the aircraft's fuel system. To achieve an additional length of refuelling hose, the base diameter of the hose drum was reduced by one outside diameter of hose, thereby creating a three-layer drum, the outside diameter of which remained the same as for the Mk 32/2800.

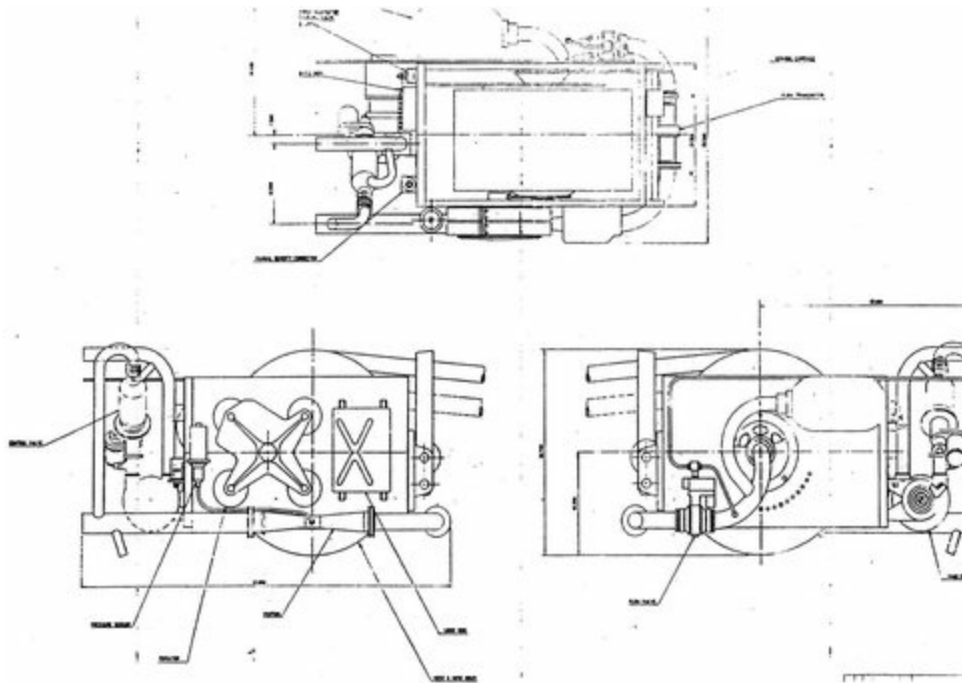
The overall dimensions of the hose-drum unit assembly were as follows:

Overall width	35.57 inches
Overall length	61.00 inches
Overall height	39.97 inches

The basic structure of the unit comprised two light-alloy

machined side plates, together with machined light-alloy end plates, thus providing a box structure. The hose drum was mounted on bearings located within the side plates, on the starboard side, incorporating a Flexibox rotating seal, and a chain-drive sprocket for the drive to the vane/motor pump and gearbox. The port side had a double chain sprocket, one of which drove the Tensator spring motor and the other the unit's hose serving carriage. The serving carriage, located at the rear of the unit, was similar to that on the Mk 32/2800, though it was

Fig. 336. Mk 34 hose-drum unit



longer in length to cater for the increased refuelling hose's length.

The hose-drum drive comprised the vane/motor pump and gearbox as used on the wing pod, together with the hose-drum control valve likewise identical; these were mounted at the forward end of the unit's assembly across the forward

end plate. The inlet and outlet ports of the vane/motor pump were positioned vertically upwards, thus permitting easy connection to the control valve and fuel-transfer system, together with the pump's return line. The Tensator spring motor and electronic logic box were mounted on the port side plate, the chain drive for the Tensator being connected to the hose drum. All the chain drives had manually adjustable chain-sprocket adjusters to maintain the correct chain tension.

The fuel-transfer and hose-drum-drive power system, shown in [Fig 337](#), was connected to the aircraft's fuel system via the separately mounted fuel pump. The hose-drum unit's fuel-transfer pipe ran along the base of the hose drum, having a venturi located beneath the Tensator spring motor, thence across the rear of the unit and below the refuelling-hose serving carriage, which incorporated a fuel-flow transmitter. The fuel pipe then turned to connect with the Flexibox rotating seal on the starboard side, also having a fuel/vent valve and a fuel-surge absorber fitted. The venturi fuel-pressure sensor was mounted on the port side plate forward of the Tensator, being connected via a small pipe to the throat of the venturi. The manual fuel-density corrector was mounted on the forward end plate, and was connected to the main fuel-transfer pipe. Adjacent to the unit's fuel-transfer-system piping two further fuel pipes were teed into it, one to supply fuel to the inlet

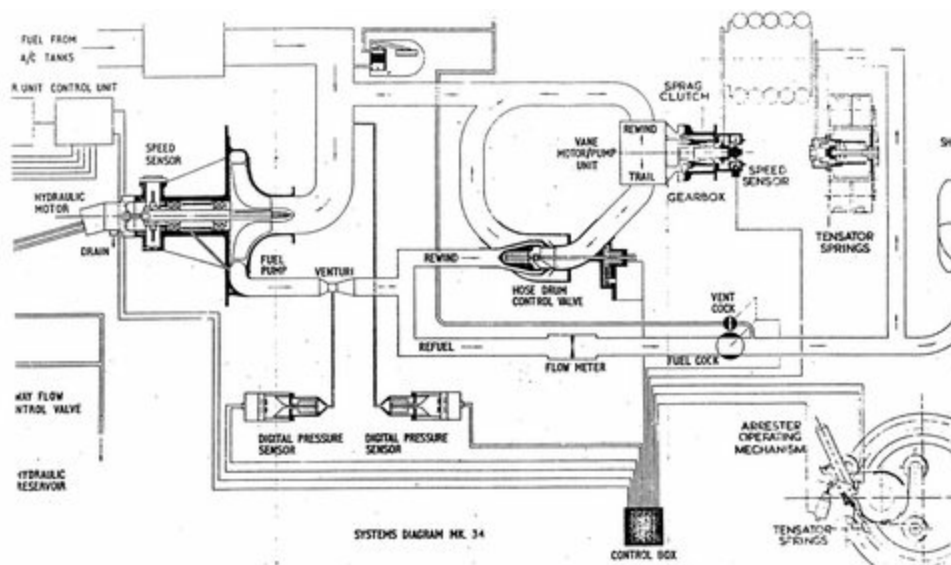
of the hose-drum control valve to provide the power for rewinding the refuelling hose, the other to a fuel-jettison valve mounted to the aircraft's structure, which in turn joined to a fuel-jettison pipe that went overboard.

The in-line outlet of the hose-drum control valve was joined to one port of the vane/motor pump, and the other outlet was mounted on the side of the valve to a fuel return pipe, which was also connected to the second port of the vane/motor pump, and thence to the aircraft system.

The operation of the unit was identical to that of the Mk 32/2800 wing pod, using the same electronic control system and control panel. The performance and the original estimated weight were as follows:

Hose-drum-unit assembly (dry)	700 lb
Hose-drum-unit assembly (wet)	785 lb
Reception coupling type	Mk 8 (British or MA2 (USA))
Hose trailed length	73 feet
Hose trailing speed	4 feet/second
Hose rewind speed	2 feet/second
Hose response speed (receiver contact)	10 feet/second
Fuel-flow transfer rate	0-350 imperial gallons/minute
Fuel pressure at reception coupling	50 psi (3.4 bar)
Electrical supplies	28 V DC 450 W
Hose trail/wind operational speeds	230-320 KIAS

Fig. 337. Mk 34 hose-drum fuel and power system



CHAPTER FORTY-ONE

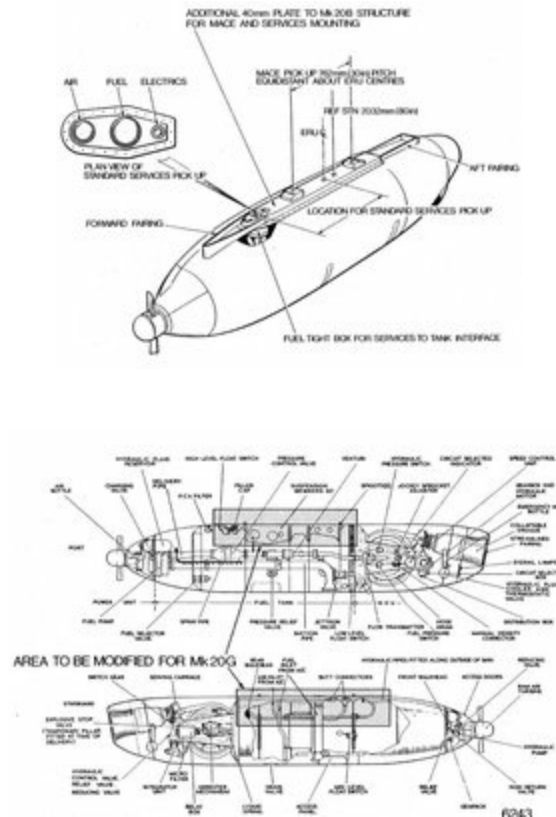
Mk 20G Refuelling Pod

During January 1984, another design study was carried out for the conversion of the Tornado aircraft into a single-point 'Buddy-Buddy' tanker. The study investigated the fitting of a modified Mk 20B refuelling pod that was designated as the Mk 20G to the minimum area crutchless ejector (MACE), and the ejector release units fitted to the aircraft's fuselage centre pylon.

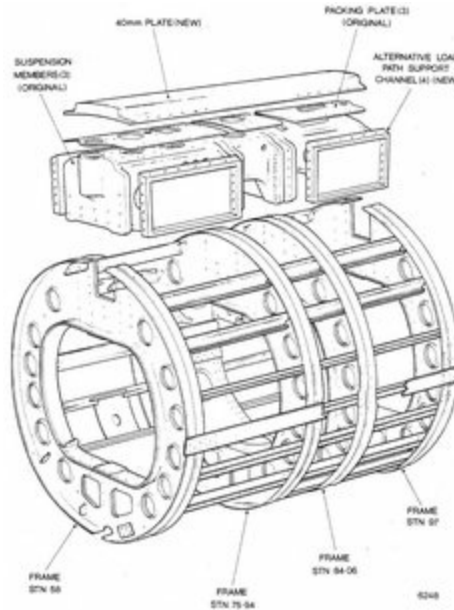
Operation of the pod was similar to that of the Mk 20B, but made use of a smaller control panel located in the rear cockpit on the port console. One of the advantages of using the Mk 20G was that the Mk 20B was becoming readily available for modification, as it could be obtained from time-expired aircraft. Also, there would be 98% of commonality, enabling existing spares to be used, and the ground servicing equipment of the pod, together with component servicing that permitted the use of 95% of the existing equipment.

To make the pod compatible with the aircraft's attachments, i.e. fuel, air, and electrical connections, the top of the Mk 20B had to be redesigned, together with some re-routeing of its internal components

To achieve compatibility with the aircraft's pylon; the top structure of the pod necessitated additional structural members to be incorporated, as shown in [Figs 338](#) and [339](#), and the repositioning of the hose-drum unit's hydraulic supply lines, as well as the re-routeing of the internal fuel-system piping, due to the aircraft's connections being at the



100



These were located on the top of the pod externally, and were bolted through the existing structure. Attached to the beam but mounted internally were four alternative load path channels, as shown in [Fig 341](#), between pod Frames 58 and 75.94, and 84.06

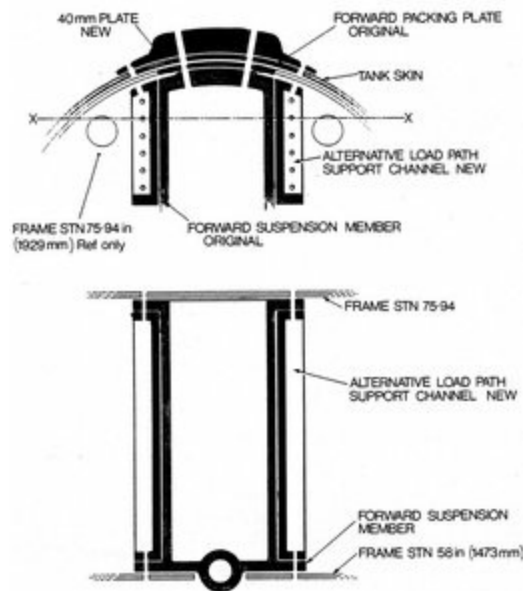


Fig. 341. Mk 20G pod, new load path channels

and 97, respectively.

The external hydraulic pipes that supplied the hose-drum unit's hydraulic power were moved 1.50 inches (50.8 mm) downwards on the starboard side of the pod to accommodate the new beam.

Re-routeing of the fuel, air and electrical connections (Fig 342), which were located internally, together with the relocation of the high-level float-switch, enabled all services to connect with the aircraft's interfaces at the forward end of the pod. All the connections through the new beam were mounted in a fuel-tight box mounted within the fuel-tank section at the top and the forward end. Also, to enable the operator to have an indication of the quantity of fuel remaining in the fuel-tank section, two capacitance transmitters were incorporated into the internal systems.

From experience gained from the Tornado during Bracket refuelling, it was found that the aircraft's refuel transfer valves 'chattered'. To overcome this problem a modified pressure control, which reduced the pressure output from it, was to be incorporated.

As the refuelling pod was now to be jettisonable (previously it had always been a fixed installation), the introduction of the standard fuel and air breakaway connections were to be incorporated, with snatch connectors for the electrical system cables.

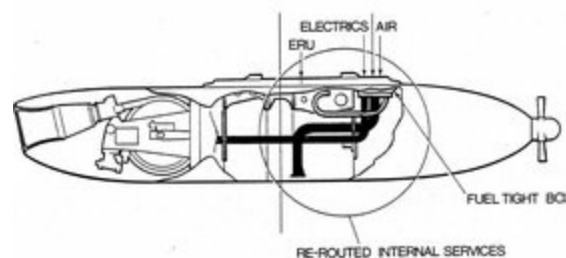


Fig. 342. Mk 20G, re-routeing internal fuel pipes

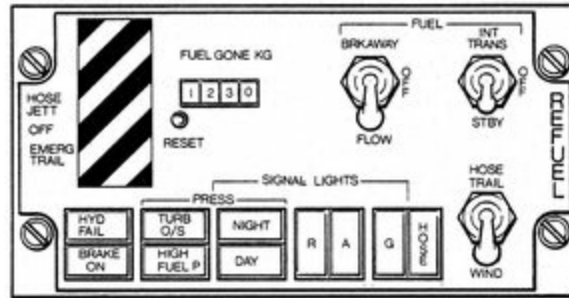


Fig. 343. Mk 20G control panel, Tornado

The control panel (Fig 343) for the refuelling pod was redesigned to suit its installation in the aircraft's rear cockpit, as shown in (Fig 344). However, all of the controls provided the sequence of operations as for the Mk 20B refuelling pod, but the overall size was much reduced.

The dimensions were:

Case dimensions	Height	73.2 mm (2.88 inches)
	Width	127mm (5.00 inches)
	Length	155 mm (6.10 inches)
Face dimensions	Height	76.2 mm (3.00 inches)
	Width	146 mm (5.75 inches)

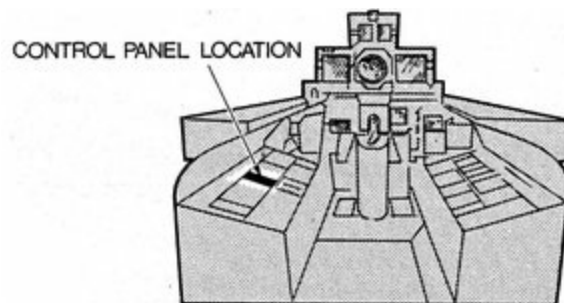


Fig. 344. Mk 20G control panel position

The following were the redesigned operating sequences:

The HOSE JETT/OFF/EMERG TRAIL switch was protected by a black and yellow guard that prevented inadvertent operation. It initiated from the centre 'OFF' position either the refuelling-hose jettison or emergency trail. When the refuelling-hose jettison was selected, the switch applied power to the refuelling-hose-jettison solenoid located inside the hose drum, thus releasing the refuelling hose from the pod. When the 'Emerg Trail' switch was selected, power was applied to the hose-drum unit's brake mechanism, releasing the brake, and allowing the refuelling hose to trail to the full-trail position. The FUEL GONE indicator was an electromechanical unit that provided a 'Fuel Gone' indication, calibrated in kilograms, reading from 0 to 9,999. The indicator could be zeroed through a button beneath the read-out window.

The BRKAWAY/OFF/FLOW switch selected from the centre 'OFF' position either a RED warning light (contact), which was duplicated on the control panel, instructing the receiver pilot to disconnect, or to power the fuel-selector valve to permit fuel flow when a receiver made a contact after the refuelling hose had been pushed in sufficiently to make the required electrical circuits.

The INT TRANS/OFF/STBY switch, selected from the centre 'OFF' position, either enabled the tanker aircraft to use the fuel contents or provided supplies necessary for the pod's operation, and was in that respect the master selection.

The HOSE TRAIL/WIND switch initiated the refuelling-hose trail or wind when either was selected.

The HOSE light showed as a plain white light, which was either steady when the refuelling hose was fully wound in, or flashing when the refuelling hose was moving in either the trail or wind sequences.

The R A G (RED, AMBER, and GREEN) indicators provided the operator, and the receiver pilot through duplicated lights on the pod's rear fairing, the sequence of the pod during the refuelling operation.

The RED indicator showed that the operation had been initiated and that the refuelling hose was either in 'Trail' or 'Wind' after a refuelling, or that the operator had selected BRKAWAY to indicate an emergency.

The AMBER indicator was automatically illuminated when the refuelling hose was at the full-trail position, and high gear selected on the hose-drum unit.

The GREEN indicator was illuminated when the receiver had pushed the refuelling hose in the 5-7 feet indicating the the fuel flow from the pod had commenced.

The DAY/NIGHT indicator, WHITE or BLACK (with white legend) respectively, permitted the operator to select the intensity of the pod's contact lights. Either half of the indicator would illuminate, according to the selection made.

The HIGH FUEL P/TURB O/S indicator, AMBER or RED respectively, provided the operator with a warning of high fuel pressure and turbine overspeed in the event of either or both occurring. Reset was available for the HIGH P by pressing the indicator, thereby reopening the pressure-control valve, which normally closed when high fuel pressure occurred. There was no reset for TURB O/S: the turbine speed was governed by a mechanical governor, and the turbine overspeed indicator detector reverted to normal, extinguishing the O/S indicator when the overspeed condition was passed.

The HYD FAIL/ BRAKE ON indicator, RED or BLUE respectively, provided a warning in the event of total hydraulic pressure failure, and an indication that the hose-drum brake had been applied. The BRAKE ON indicator did not illuminate when the mechanical full-trail brake operated.

The normal power supplies to the control panel were 28 V DC for the services and indicators controlled or mounted on the panel, and 115 V AC 400 Hz for the electroluminescent light plate. The leading particulars for the Mk 20G refuelling pod were:

Overall Dimensions

Length of pod	415.8 cm (13 feet 7 inches)
Diameter of pod	71.12 cm (28 inches)
Length of refuelling hose	1,554 cm (51 feet)
Diameter of drogue	71.12 cm (28 inches)
All-up weight (dry)	525.90 kg (1,157 lb)
All-up weight (wet)	1,000 kg (2,209 lb)
Capacity of fuel tank	652.5 l (145 imp gallons)
Unusable fuel	45.5 l (10 imp gallons)
Fuel transfer rate	538.6 kg/min (1,185 lb/min)
Hose end pressure	3.45 bar (50 psi)
Fuel-tank relief pressure	1.59-1.72 bar (23-25 psi)

Principal Lubricants

Power unit gearbox	OM.13 (NATO 0-134)
Hose-drum-drive gearbox	

and control system

OM.15 (NATO H-515)

CHAPTER FORTY-TWO

Lockheed Tristar

Three-Point Tanker

In June 1986 Marshalls of Cambridge (Engineering) Ltd put forward a proposal reference MCE/TP/528A for the conversion of the Tristar single-point tanker into a three-point tanker. This was to be achieved by the addition of two wing refuelling pods, the pods to be a variant of the Mk 32/2800 refuelling pod and designated as the Mk 32A.

The initial study for the conversion was at which position on the wing the pod should be located. It was concluded that Station 741 was a possibility, with a longer hose incorporated in the refuelling pod. This station was more favourable from the point of view of the effects of flutter impact and low aerodynamic interference, as well as having been noted in previous flight trials as exhibiting little of the marked wing-flexing characteristic of the outboard wing Station 845.

It was not only the outboard (741) wing position that was important, but also the vertical location, to avoid the wing slat and flap positions when in use. The geometry of their positioning is shown in [Fig 345](#), which displays the maximum slat operating position and 33 degrees of flap operation at the rear of the wing.

With this wing position a longer refuelling hose would have to be incorporated in the refuelling pod to ensure that the receiver pilot when in the refuelling position could still observe the tanker's tailplane. It

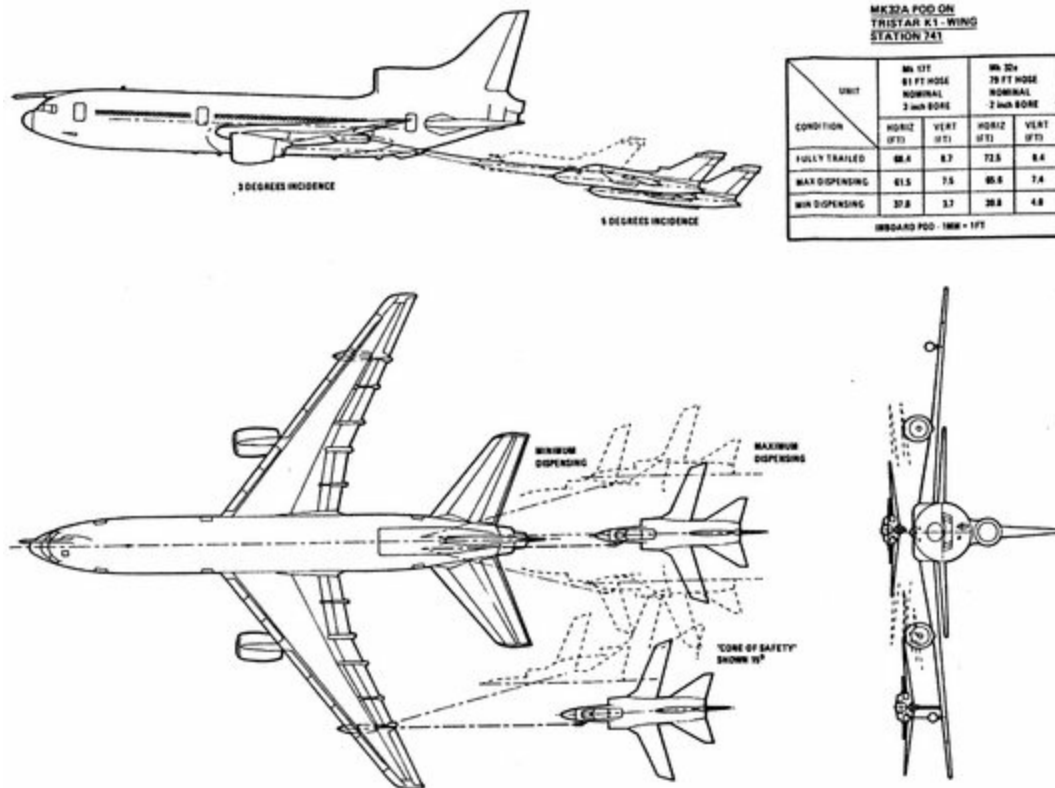


Fig. 345. Lockheed Tristar wing refuelling pod proposal

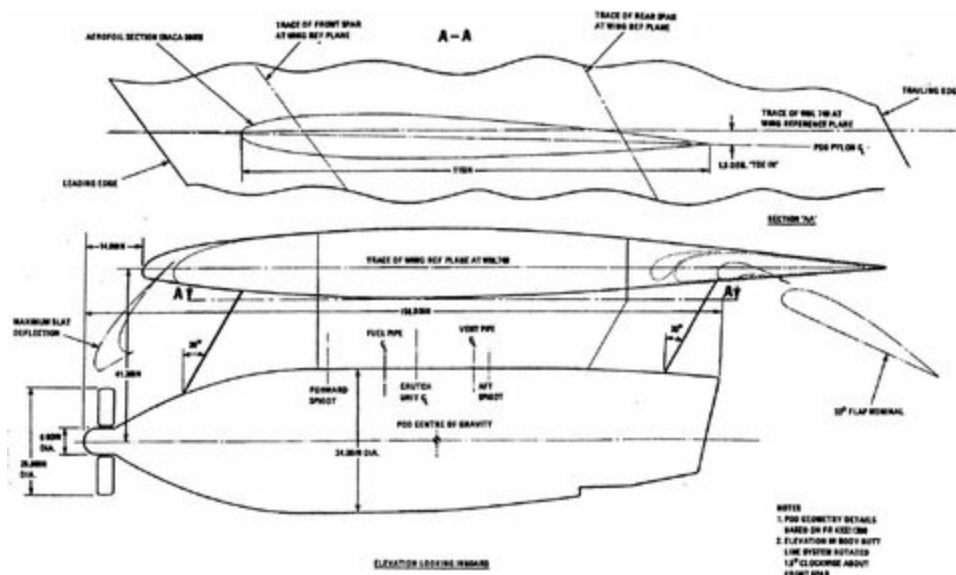


Fig. 346. Lockheed Tristar Three-point Tanker Pod Locating Geometry

was concluded that a 79-foot hose would be required, and the question of its stability was considered. To investigate the stability and provide confidence in the longer hose, a flight trial was to be arranged to trail the new length of hose from a VC10 Mk 17B package. This did not happen, but a trial did take place using a Victor tanker and was very successful.

The wing pylon would comprise three main sections: the main load-carrying central box section, which extended between the wing front and rear spars, a leading nose fairing and a trailing-edge fairing.

The central box section comprised an inswept, machined front spar forming its front end, and provided support for the pod's forward spigot location and the attachment for the leading nose fairing. The top end of the fitting provided the main attachment point to the wing via two tension bolts. On to the rear face of this main spar was attached a box assembly comprising two machined side plates and a machined end plate, these formed the mounting for the pod crutching and suspension unit. A raked, machined rear-end spar fitted beneath the wing's rear spar formed at its aft end provided support for the pylon to the wing's rear attachment trunnion. The top of the pylon would be closed off with a flat machined 7075 rib running between these two spars, which also provided the attachment for the pylon side skins, the pylon to wing underside fillet fairings and pylon-towing aft attachment. The bottom of the pylon would incorporate a machined sole-plate running the complete length of the pylon, interfacing with the spar fittings and crutching support box. The pylon would also incorporate the mechanical, electrical, fuel-supply and venting-interface requirements for the refuelling pod. The pylon assembly is shown in [Fig 347](#).

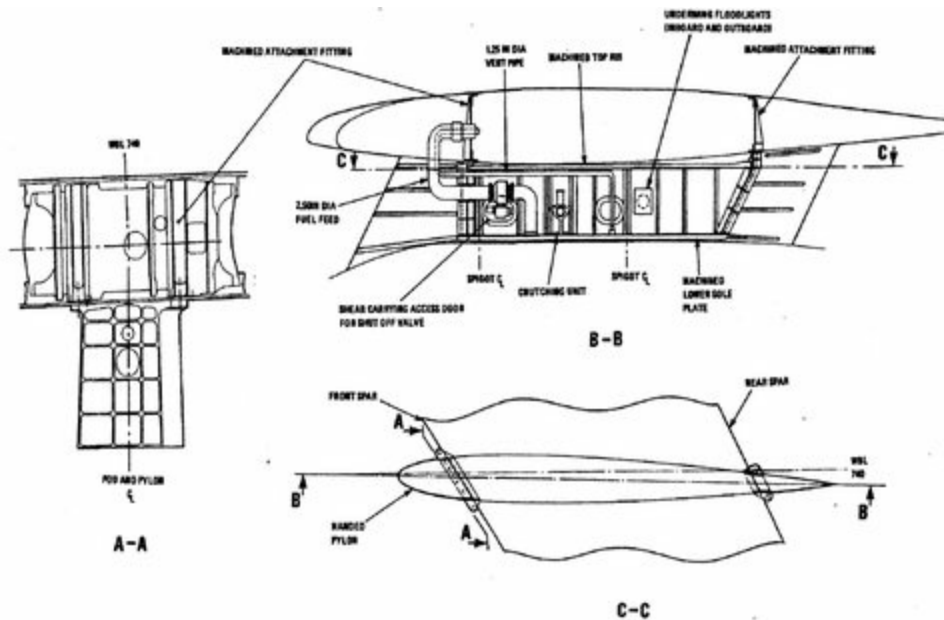


Fig. 347. Lockheed Tristar three-point tanker wing pylon

A study of the K Mk 1 and K Mk 2 Tristar tanker's fuel system indicated that the fuel-pumping capacity of the existing low-pressure pumps to the Mk 32A wing pods was incapable of supplying the 2,500 lb/min (312 imperial gallons) with a hose-end pressure of 50 psi (3.4 bar). This was due to the relatively large pressure drop in the refuel/defuel line, and if fuel was not available in both wing and fuselage tanks individually, it would be less than 1,900 lb/min (238 imperial gallons). Wing and fuselage had a similar capability in this regard as, although the feed wing-to-pod was shorter than fuselage-to-pod, the wing pumps also supplied the aircraft's engines, as well as providing the motive flow for the tank scavenge ejectors, which also reduced the pressure available from these pumps.

A flow rate of 1900 lb/min was acceptable, as the refuel/defuel line had inadequate strength to withstand a likely fuel surge pressure. The diameter was therefore to be increased from 2¾ inches to 3½ inches, being the maximum practical for post-production installation. However, this

configuration failed to meet the specification requirement by a relatively small margin.

The Ministry of Defence review of 9 May 1986 concluded that if the dual Mk 17T hose-drum unit and pod dispensing was to be limited to the operational emergency case, then logically the three-point dispensing, which had previously been considered could be excluded. They also required to be advised on the fuel-pumping performance available under various conditions. This was to disregard the specification requirements so that a judgement could be made on the revised configuration above without additional fuel pumps in Tanks 1A and 3A, which had been proposed previously.

The revised configuration for the fuel-supply line to the refuelling pods is shown in [Fig 348](#).

A complete programme for the development of a Tristar three-point tanker was proposed, together with the support of Lockheed and Flight Refuelling Ltd. However, after the large amount of work the study had entailed the concept did not come to fruition.

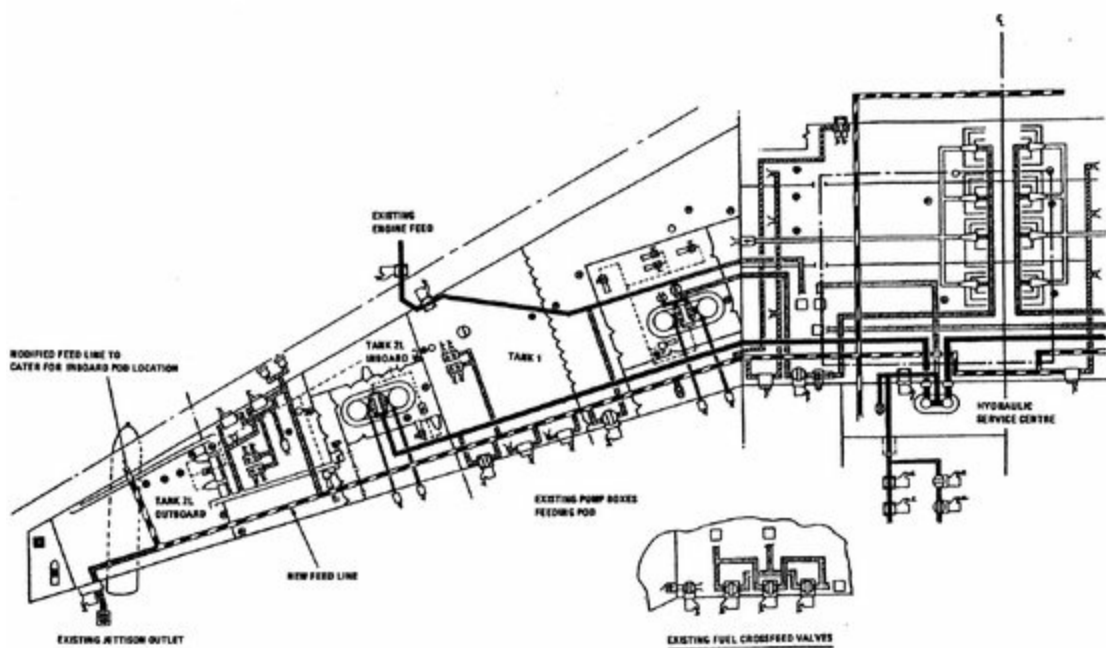


Fig. 348. Lockheed Tristar three-point tanker wing-pod fuel line

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Index

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B-66
B-50
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Boeing KC.
Boeing 707
BristolBrabazon
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British Aerospace Tornado
Bristol Fighter
Consolidated B.24 Liberator
Convair B.36
Curtis Robin
Dassault Mirage
Dassault Mirage 2000
de Havilland
de Havilland
de HavillandAlbatross
de HavillandSea Vixen
de Havilland Comet

Douglas Biplane
English Electric Camberra Mk
English Electric Lightning
F.4 Phantom
F.14 Tomcat
F.18 Hornet
F.66
F.86 Sabre
Farman 2234 Bomber
Flight Refuelling FR.10
Flight Refuelling FR.11
Flight Refuelling FR.12
Fokker Trimotor
Gloster Javelin
General Dynamics F.106 Delta Dart
Gloster Meteor Mk
Gloster Meteor Mk
Gloster Meteor Mk
Gloster Meteor NF.
Grumman A.6
Grumman EA.6
Grumman F.14 Tomcat
Handley Page W.10
Handley Page Harrow
Handley Page Hasting
HandleyVictor
Handley
Hawker Hart
Hawker Hunter
Hawker Sidley Harrier
Latecoere Flying Boat
Lockheed.130 Hurcules
Lockheed Tristar, ,89, 90
McDonnell Douglas A.4 Skyhawk
McDonnell Douglas F.101.A. Voodoo
McDonnell Douglas KC.10 Extender
Republic F.84E Thunderjet
Saro Windhover
Short 'C' Class Flying Boat
Short May Composite
Short Stirling
Short Belfast
Sky Warrior
Vickers B/17
Vickers Supermarine Scimitar
Vickers TSR.2
Vickers Valiant
Vickers Valencia
Vickers Victoria
Vickers

Vickers Virginia
Westland Wallace
Westland Wessex

Personnel

Alabaster, R.C.
Allison, Percy
Ashenden, David
Ahsover, David, A.F.C.
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Beaverbrook, Lord
Beetham, M.J., Marshal of the Royal Air Force
Behennah, Frank
Bristowe, Alan
Bennet, D, Air Vice Marshal
Brabazon, Lord
Burgoyne, Harold, Flt Lt
Caparoli, Dr
Chilcot, Ben
Cimimera, M
Clark, Robin
Coates, Kenneth
Cobham, Alan, Sir
Cobham, Michael, Sir
Collier, P
Counter, C.F. Sqn Ldr
Croot, A
Cunningham, John Gp Cpt
Craig, David
Craid, David, Air Chief Marshal
Cruddas, C
Doris, Harry, Col
Fibley, Wing Cmdr
Funnel, R.A.
Gates, Roy
Gilbert, Joseph, Sir, Air Marshal
Groenen, Sergeant Adj
Goodliffe, A.W.
Goodyer, G., Air Commodore (RTD)
Grooji, Louis, Adj Aviator
Gouge, Arthur
Hagg, Arthur
Harry, Norman

Harcourt-Smith, Sir, Air Marshal
Helmores, W, Sqn Ldr
Henson, Ronald
Henriksen, I
Hornidge, P.R.
Ingle, K
Jackson, Dale
Jenks, G
Johnson, Hugh, Flt Lt
Kane, Thomas
Kay, Al
Kay, Fred,
Latimer-Needham
Lympsey, S
Lloyd, Derek
MacGregor, P.S.
Major, S.A.C.
Margaret, Princess, H.R.H.
Marks, Thomas
Morris, Philip
Marshal, Arthur, Sir
Martin, C. Mrs
Mayo, R.H. Major
Medget, John
O'Brien, Forest
Preston, Dennis
Proctor, Peter
Revell, G
Richter, J.P. Lt
Richie, Col
Rogers, Kelly, Captain
Schilling, Col
Skurja, G.M.
Smith, L.H. Lt
Smith, Harry
Spaatz, Carl, Major
Stagg, Dudley
Saltrick, Kenneth
Tanner, Richard
Thompson, John
Trilloc, C
Tuxford, Sqn Ldr
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Van, Caudenburg
Victor-Bruce, Hon Mrs
Tyson Geoffrey
Vaughn, M
Ward, G
Wakefield, Lord
Wallis, Ernest, Sqn Ldr

Weiss, Piere, Captain
Withers, Flt
Woodcock, Terence
Young, Roy